Dynamic Multi-Modality Fused Imaging, Analysis, Computer Aided Diagnosis System

Patient Anatomy And Physiology — 12

Medical Knowledge
Clinical History
Clinical Protocol

- Anatomical
- Physiological
- Molecular
- Disease Processes
- Organ System Physiology

Dynamic Multi-Modality Imaging System — 14

Anatomical
X-ray VCT

Functional and Molecular Imaging
NM/SPECT
PET

- X-ray VCT Images
- PET Isotope Images
- SPECT Isotope Images
- Dynamic Timing & Physiological Monitor Data

Multi-Modality Fused Imaging Analysis and CAD — 16

Image Analysis

Computer Aided Diagnosis

General Population History Reference Standards

Preventive Medicine & Patient Therapy Planning System — 18

Feed Back to Patient

10

Figure 1

Multi-Modality Imaging System with Common Focused 2D Curved Detector
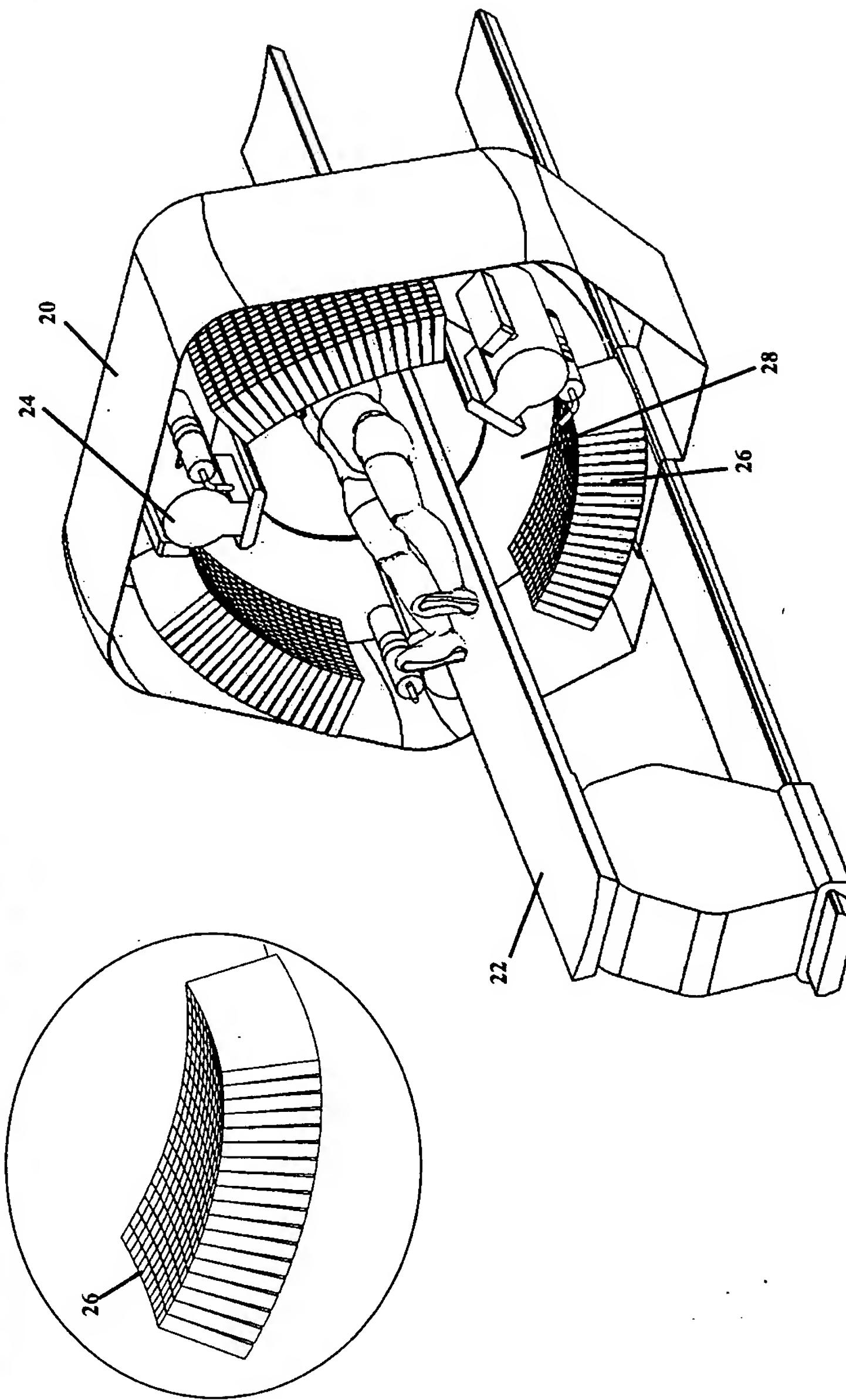
Figure 2

Overall Multi-Modality Imaging System Block Diagram

Image Analysis and Display System 64

Computer Aided Diagnosis System

Operator Real Time Image Display & Analysis Sys. 66

Image Server and Storage System 80

Interventional Image Control System 70

Physiological Acquisition (EKG, Respiratory) 78

Image Reconstruction System 62

Operator GUI and Protocol Control/System 40

DAQ Control System 42

Planning System 44

Dynamic Timing Control System 46

Gating Control System 48

MCA & PET/SPECT Framer System 68

DAQ System 50

X-Ray Control System 52

Motion Control System 54

Contrast Power Injector 56

Interventional Robotic System 58

Raw Data Management and Storage System 60

22 20 24 26 28 30

Rotor DTN 72

Slip Ring DTN 74

Stator DTN 76

Legend

Timing and Gating Synchronization

Raw Data and Image Data

Control Bus

Figure 3

X-ray & Focused 2D Curved Detector Arrangement

28

X-RAY CONE BEAM

24

X-RAY FOCAL SPOT

26
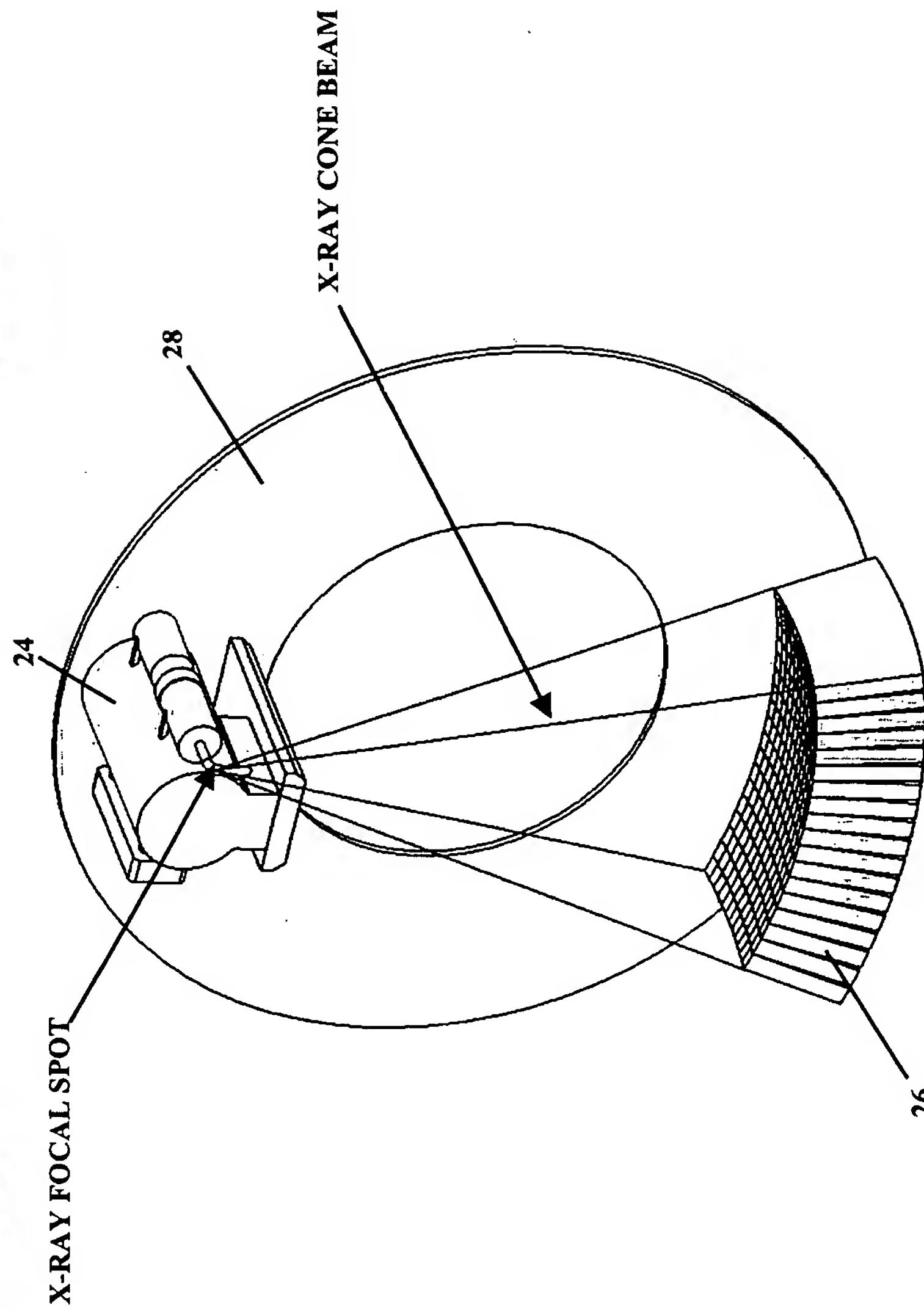
Figure 4

Cone Beam Source Collimation & Cone Beam Shaped Filter

X-ray Intensity after Attenuation by Cone Beam Shaped Filter

Fan angle across shaped filter

FIG. 5b

Intensity after Attenuation by Shaped Filter and Patient

X-ray Dose and X-ray Intensity Normalized Across Patient Projection

Fan angle across patient and shaped filter

FIG. 5d

82

26

Z

FIG. 5a

82

26

Z

Shaped Compensation Filter
Exploded View

84

Cone Beam Source Collimation

X

82

84

X

Exploded View

FIG. 5c

82

84

26

30

X

82
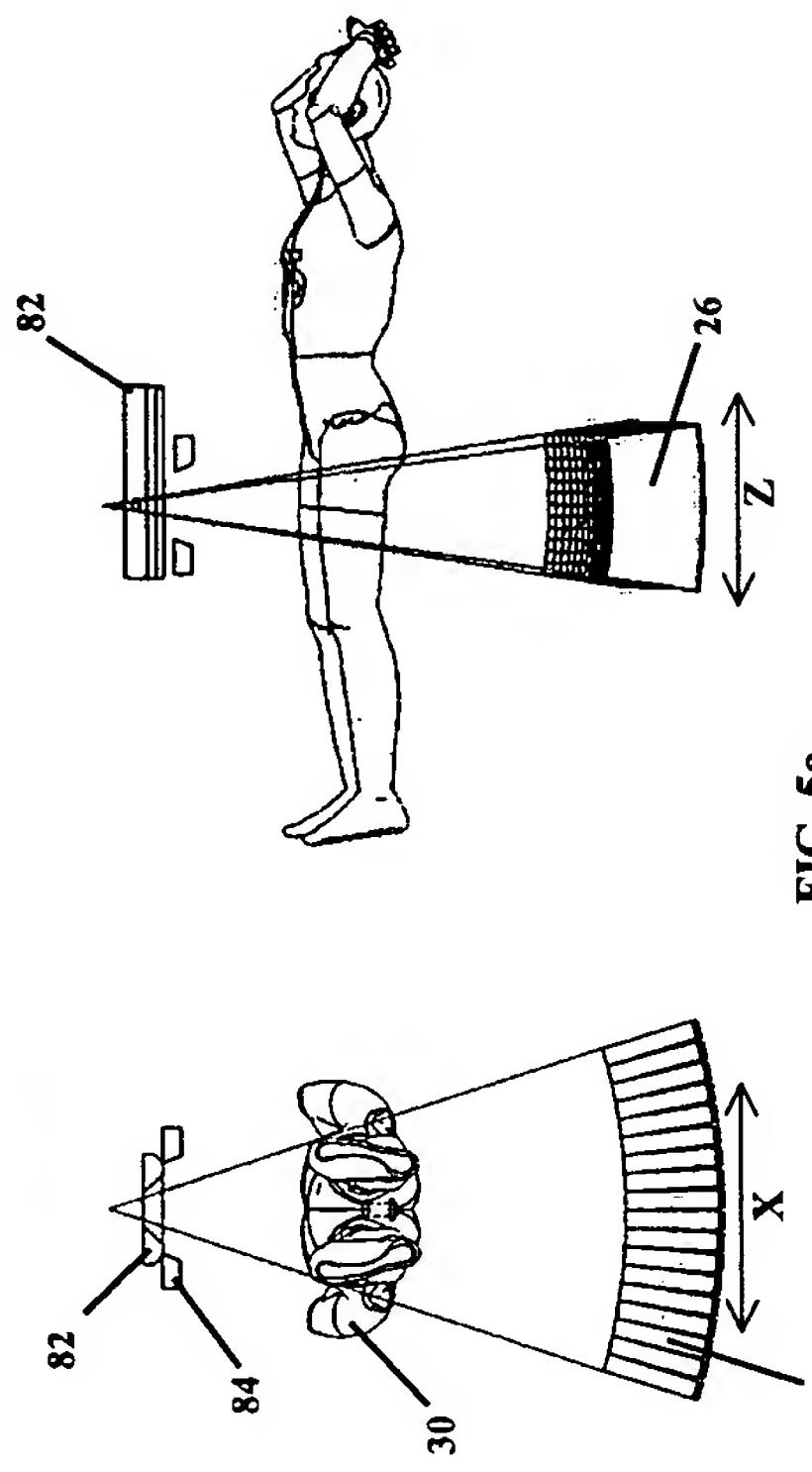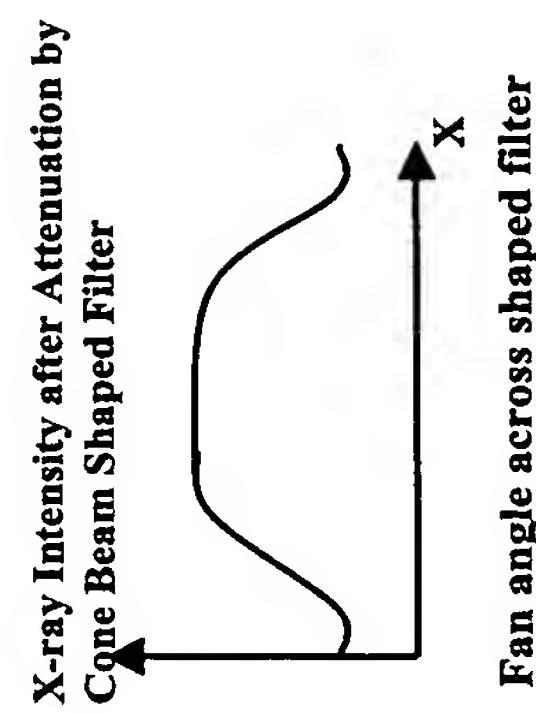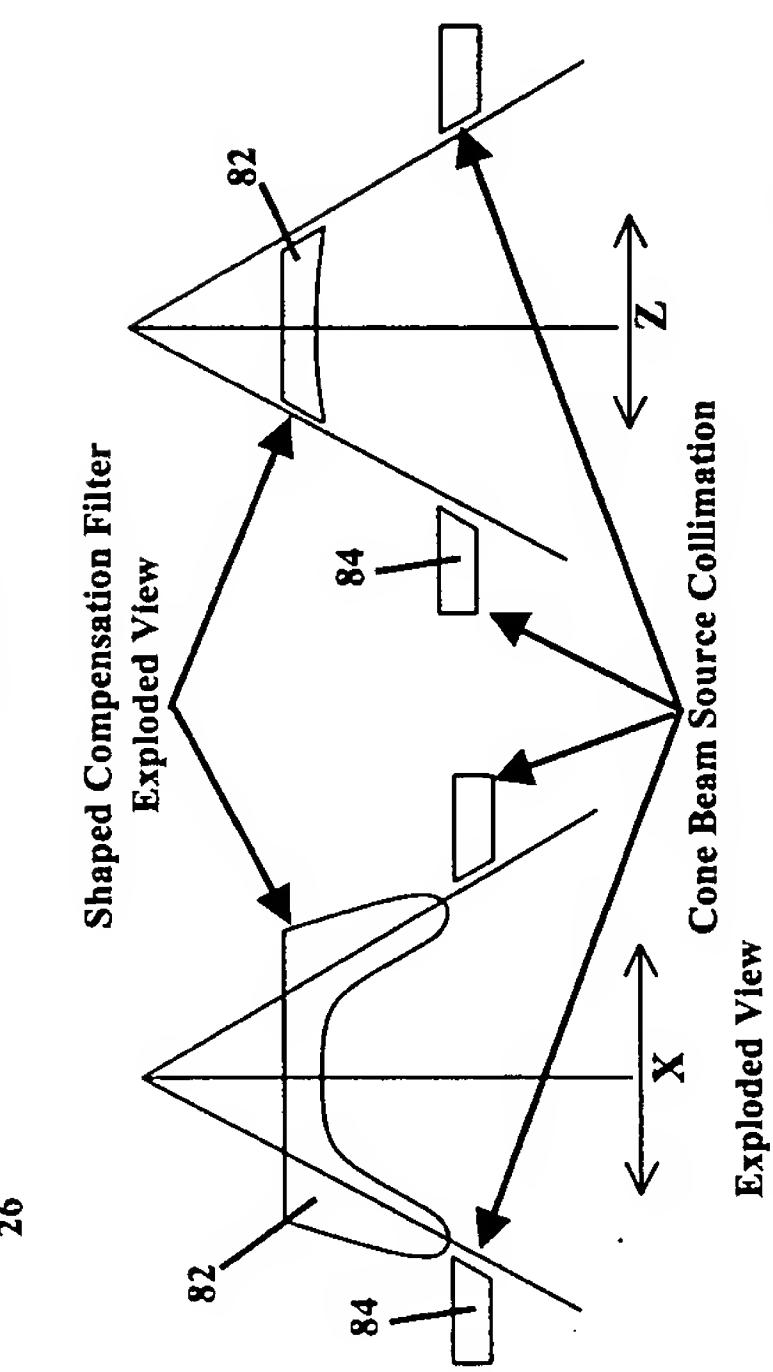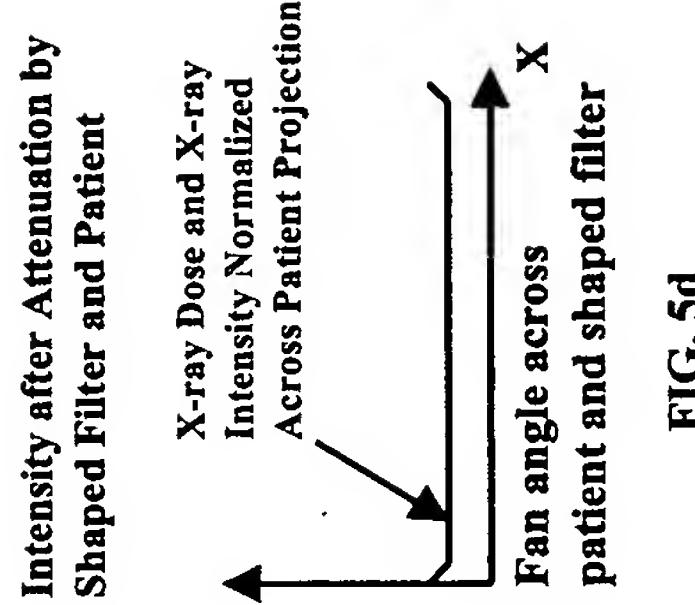
Figure 5

X-ray Cone Beam Focal Spot - Curved Detector Optics

Curved Detector to reduce spatial resolution loss and Best Conversion efficiency of X-ray
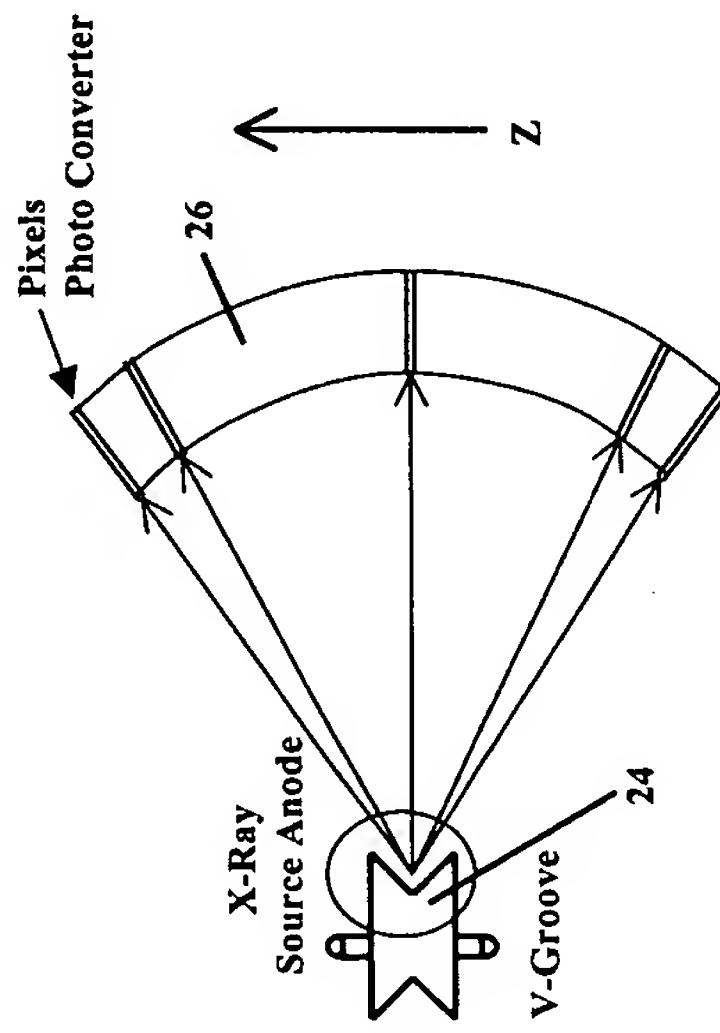
**Focal spot from V-groove Type Anode has similar spot size appearance**

Position of Cone Beam with respect to Z axis

V-groove X-ray Anode

+Z max

20°

-Z max

24

Spatial Impulse Response

+Z max

0 Z

-Z max

Spatial Resolution

FIG. 6b

Position of Cone Beam with respect to Z axis

Traditional Slant X-ray Anode

+Z max

-Z max

24

Spatial Impulse Response

+Z max

0 Z

-Z max

Spatial Resolution

FIG. 6c

Pixels
Photo Converter

26

X-Ray Source Anode

V-Groove

24

Z

FIG. 6a

Pixels
Photo Converter

26

X-Ray Source Anode

V-Groove

24

X

FIG. 6a

Figure 6

2 Dimensional Focal Spot Dithering for Improved Cone Beam Spatial Resolution

## X-ray Focal Spot Geometric Dithering For Doubling the Spatial Sampling Rate

Focused 2D Curved Detector

Center of Scan Circle

2 times the sampling rate

Normal Sampling

Dither to Improve Sampling

Figure 7b

Figure 7c

26

24

X-ray Focal Spot Dither Pattern

Figure 7a

2D X-ray Focal Spot Dither Pattern for 3D Cone Beam VCT

Z-axis Dither

X-axis Dither

X-axis Dither
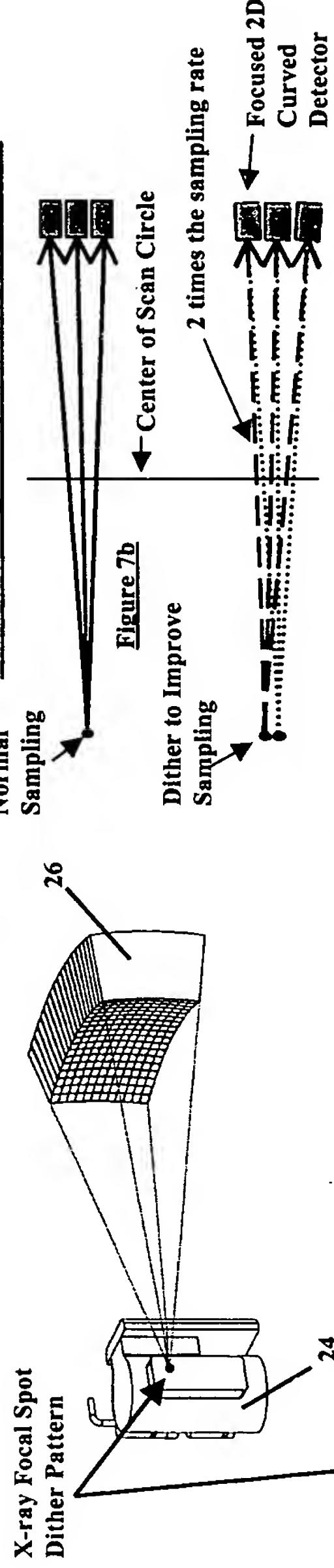
Figure 7d

Spatial Resolution comparison between Single Sampling and 2X Dither Sampling

System Frequency Response

2X Dither Nyquist Sample Freq.

2X Dither Spatial Response

Spatial Frequency Response

Normal Nyquist Sample Freq. & aliased optical response

LP/cm

Figure 7f

Optical System Frequency Response

Spatial Frequency Response
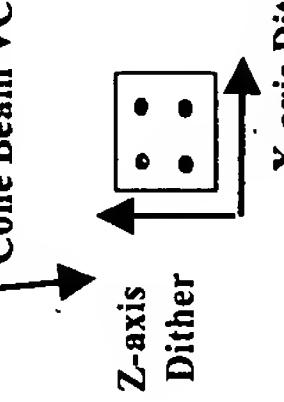
X-ray Optical System Response before Sampling

LP/cm
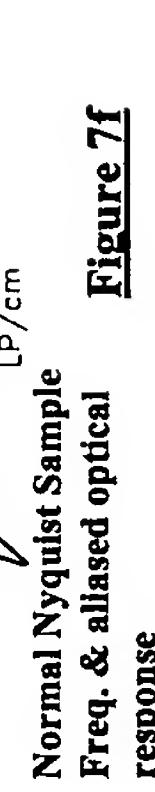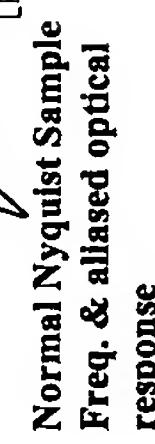
Figure 7e

Figure 7

Focused 2D Curved Detector Module

Focused Curved Detector Module

FIG. 8a

- 96 — Signal Processor and Digital Converter
- 94 — Photo Converter
- 2D Focused Collimator

90
92

FIG. 8b

90
96
94
92
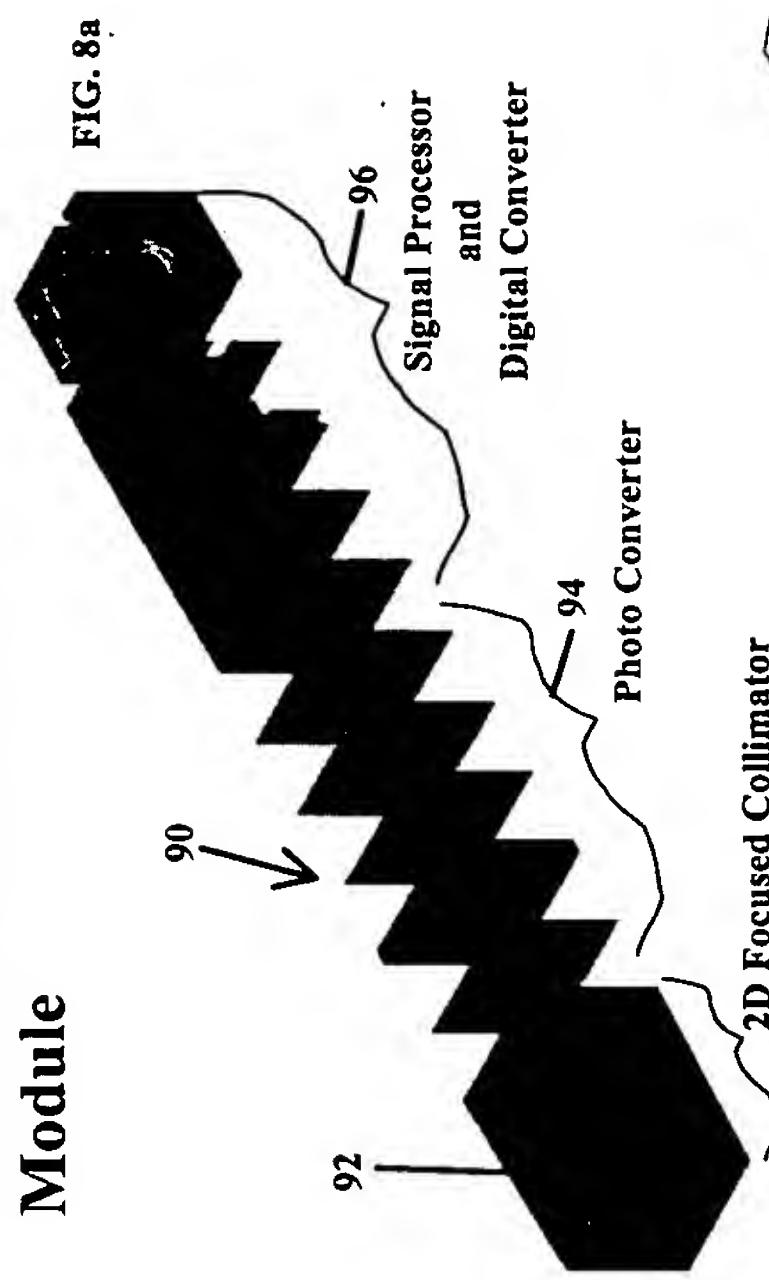
View Showing Focused 2D Anti-scatter Collimation with 2D Focused Pixels

FIG. 8c

90
96
94
92

92
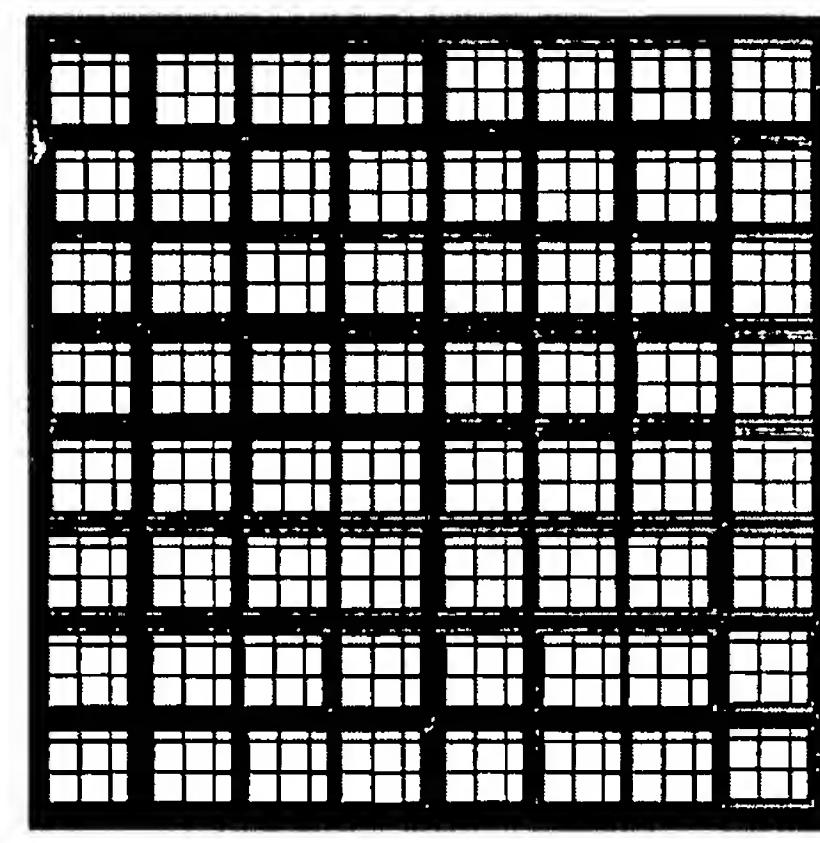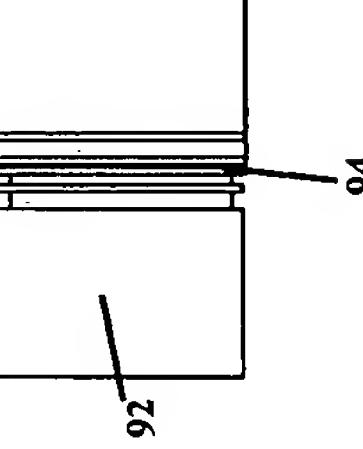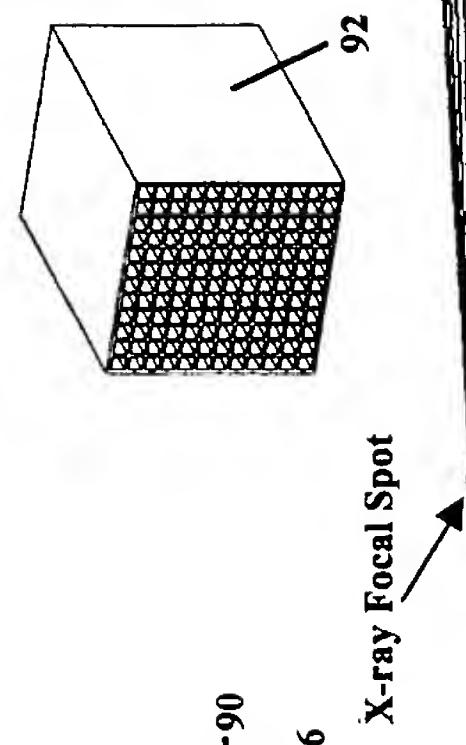
X-ray Focal Spot

FIG. 8d

Figure 8

# Focused 2D Area Detector with Adaptive Shaped X-Ray Optical Response

FIG. 9a

24

26

FIG. 9b

Detector Pixel

Impulse Response of Shaped Detector Pixel

A

B

Pixel Weighting

1	1	1
1	1	1
1	1	1

A

.2	44	.2
44	1	44
.2	44	.2

B

FIG. 9f

Impulse Response Shaping from Rectangular to Variable guassian Roll-off Function. Shaping may be Fixed or Controlled

FIG. 9c

FIG. 9d

FIG. 9e
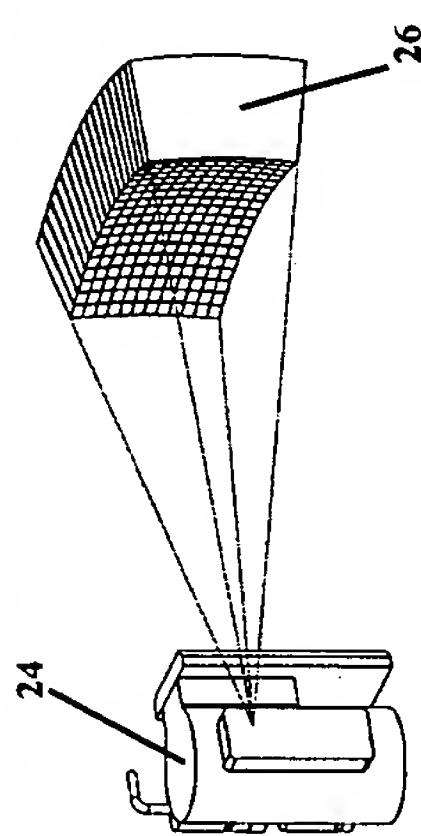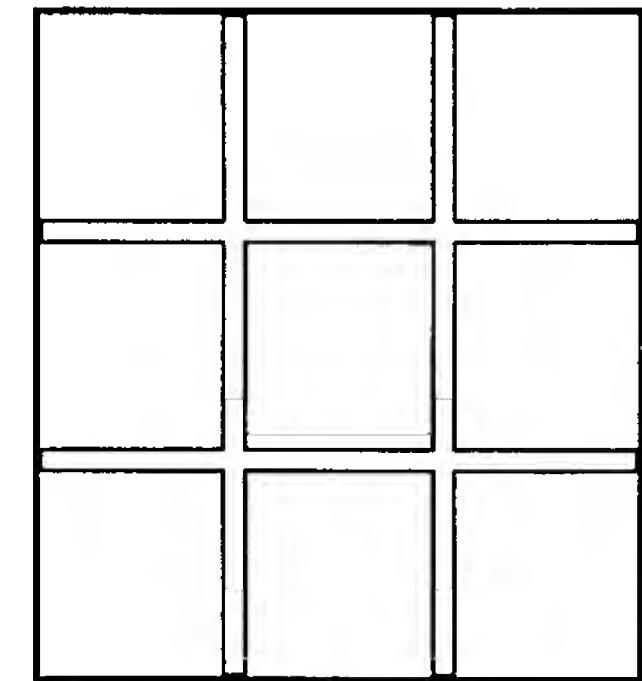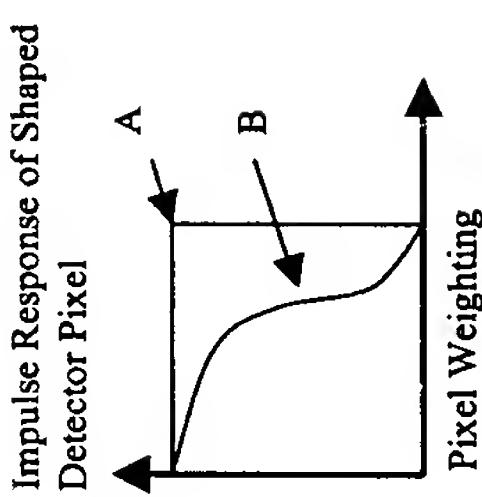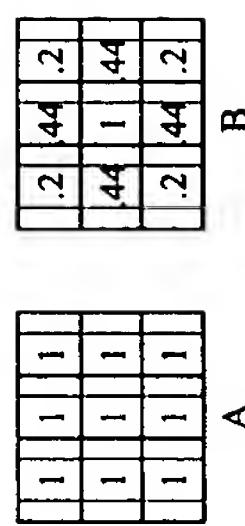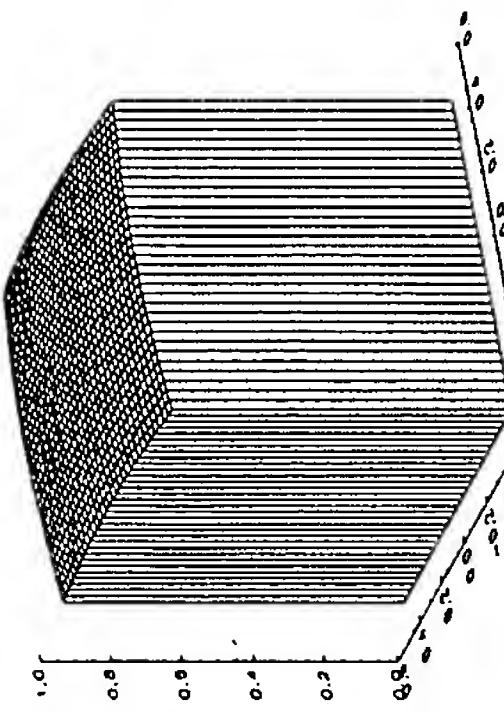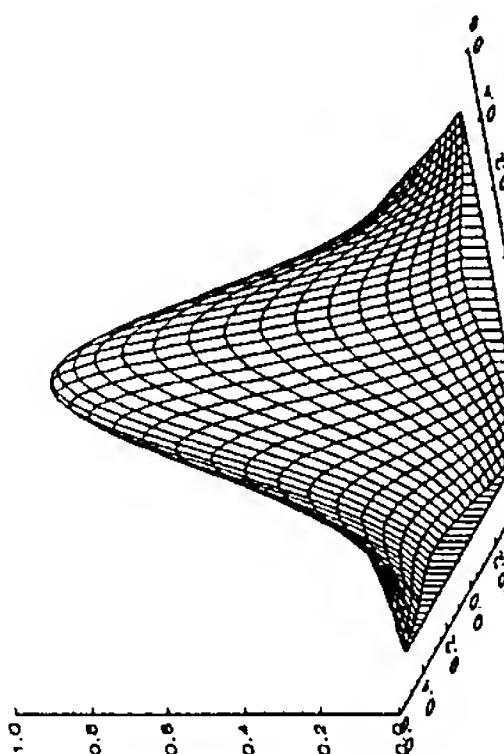
## Figure 9

Multi-Modality XGA Detector Module

X-Ray Mode

X-ray Focal Spot

FIG. 10a

PET Mode

Positron Annihilation

Gamma Ray 1

Gamma Ray 2

Coincidence Detection and
Line of Response Generation

LOR
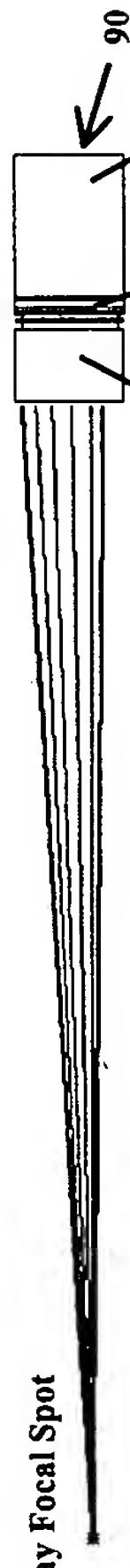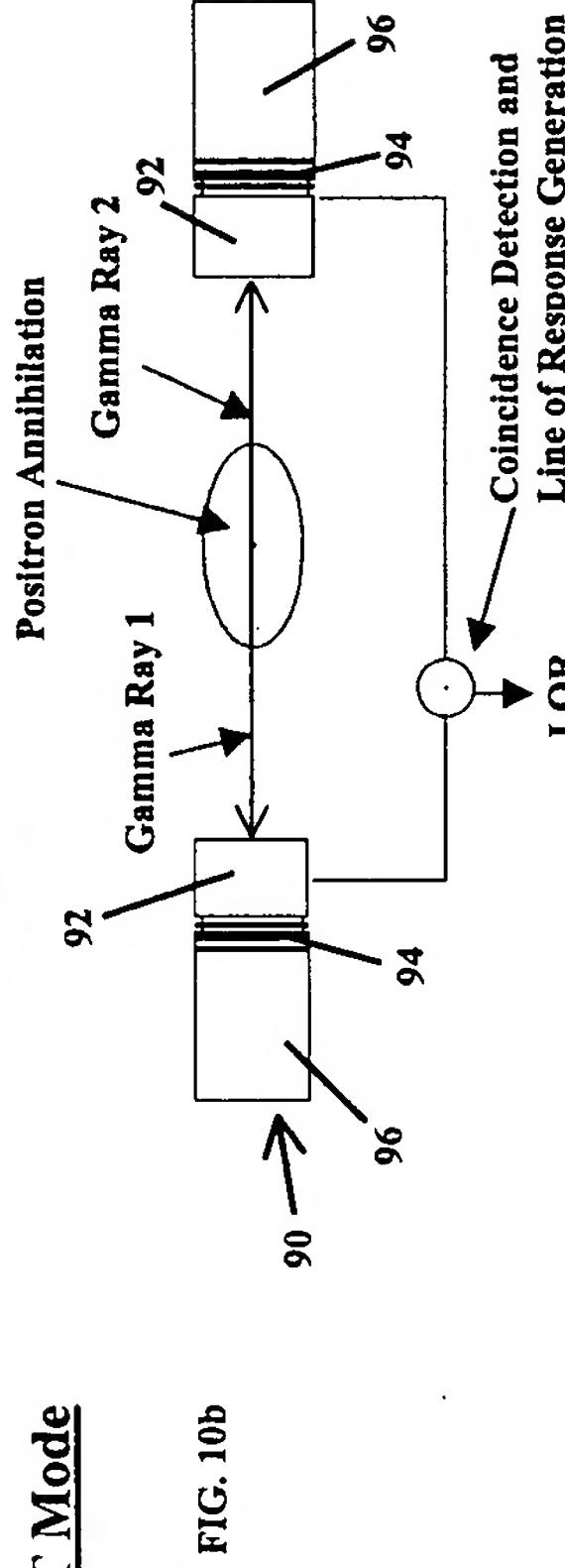
FIG. 10b

NM/SPECT Mode

FIG. 10c
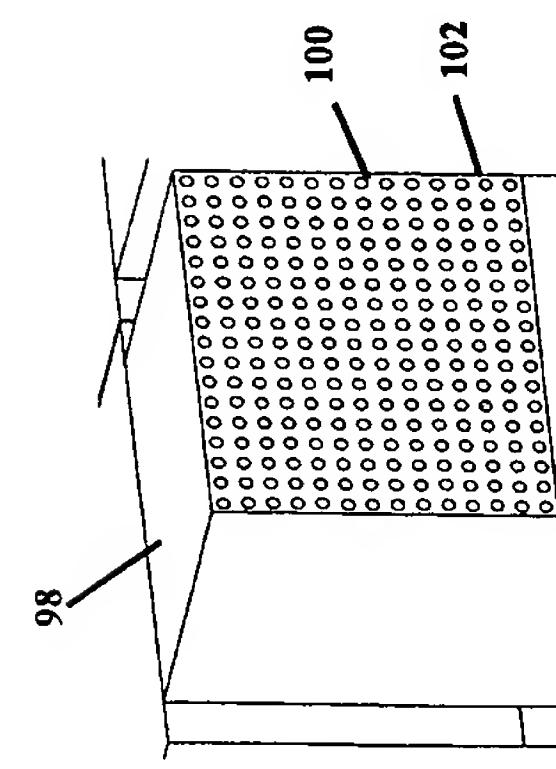
Figure 10
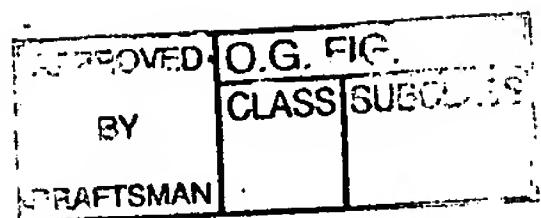
Detector Module Multi-Modality Collimation

Collimation Section Focused for X-ray Scatter Rejection

92

FIG. 11a

X-RAY MODE

X-ray Focal Spot

Collimation Section as Above for Gamma Camera Collimation at Lower Energies

92

FIG. 11b

Radiation From SPECT Isotopes

NM/SPECT MODE

Focus Vertex
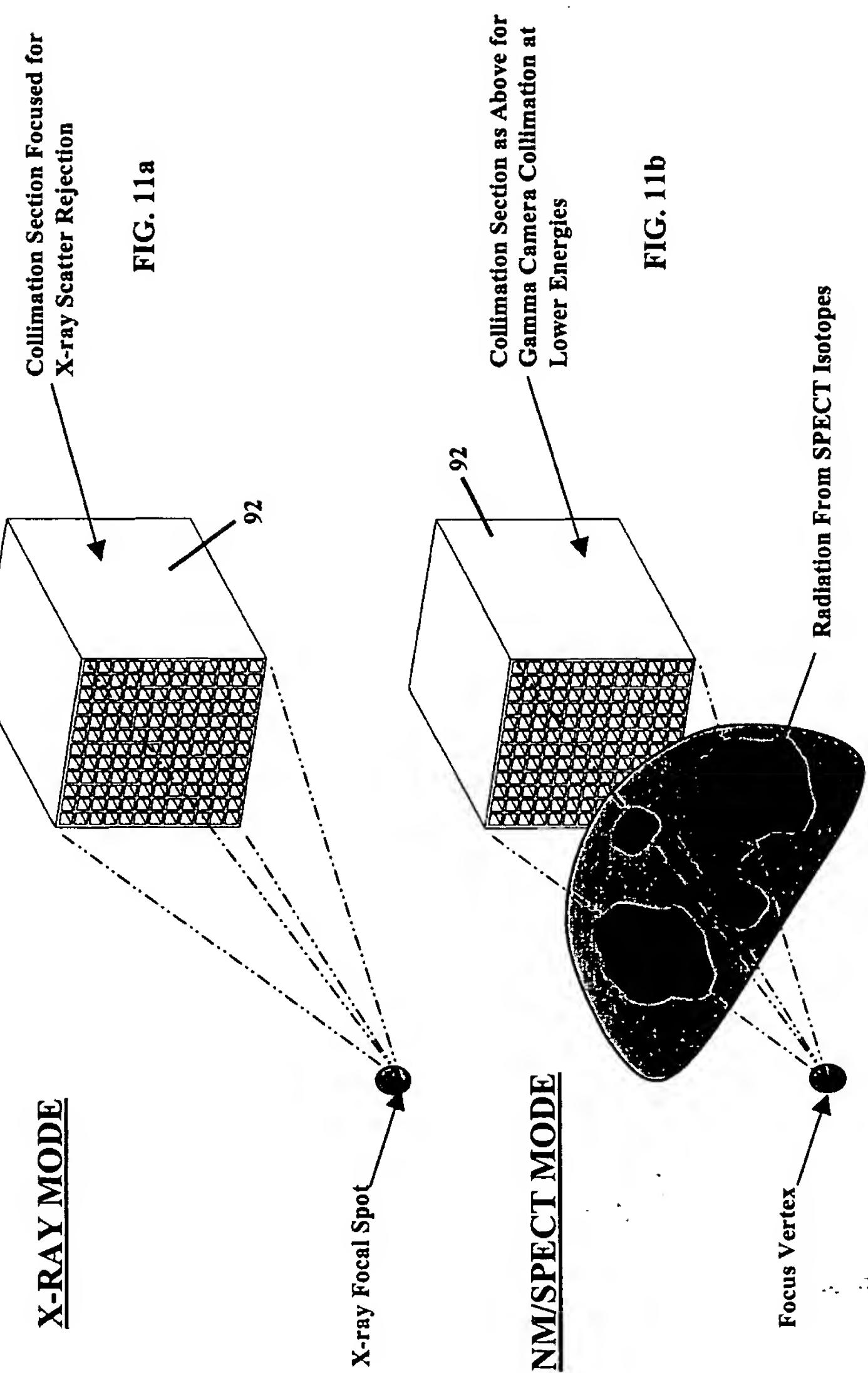
Figure 11

XGA Detector Module Signal Processing

Synchronous Sampling

X-Ray Mode

X-Ray → Photo Converter (110) → Pre Amp (112) → Signal Processing & Integration (114) → A/D (118) → Sampled X-ray Intensity

Synchronous Sampling (116)

Gating Control (48) → Synchronous Sampling

Rotate Position
Traverse Position
Physiological Gating (EKG)

FIG. 12a

Asynchronous Sampling

NM/SPECT Mode

Gamma Ray → Photo Converter (110) → Pre Amp (112) → Signal Processing and Integration (114) → A/D (118) → Sample Energy

→ CFD (120) → Threshold Level Trigger (122) → Time Stamping (124) → Sample Time

Integrate Control

FIG. 12b

Coincidence Detection

PET Mode

Sample Time 1 → Digital Coincidence (126) → LOR Generation (128) → LOR of Response

Sample Time 2

90 → 180 Degree Opposed Detector Detecting Coincident 511 KEV Gamma Ray

92
94
96

FIG. 12c

Figure 12

System with Optional PET Anti-Scatter Baffle

Z-Axis Septa in PET
Anti-Scatter Baffle
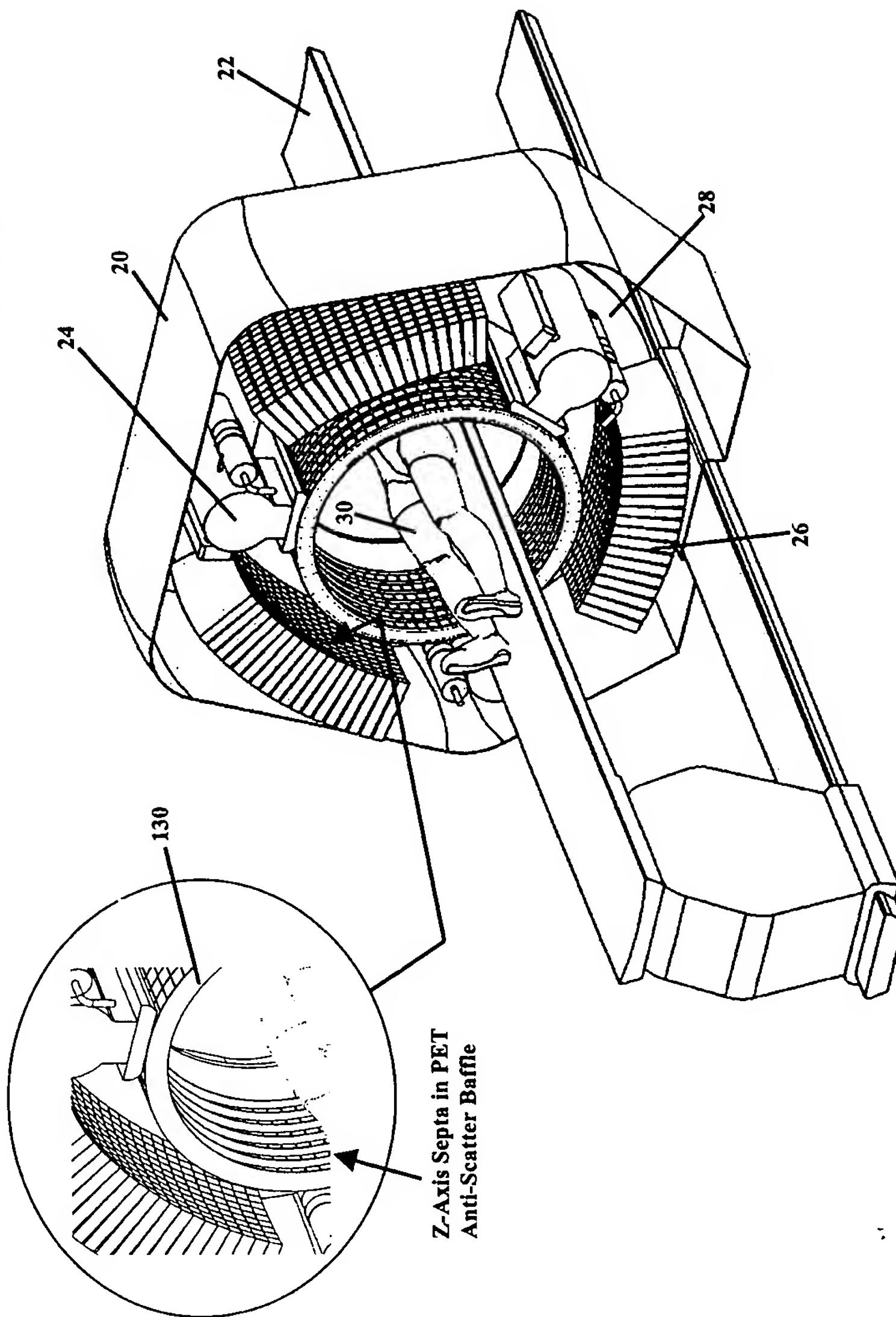
Figure 13

PET – Anti-Scatter Baffle SEPTA

24
28
26
130
130
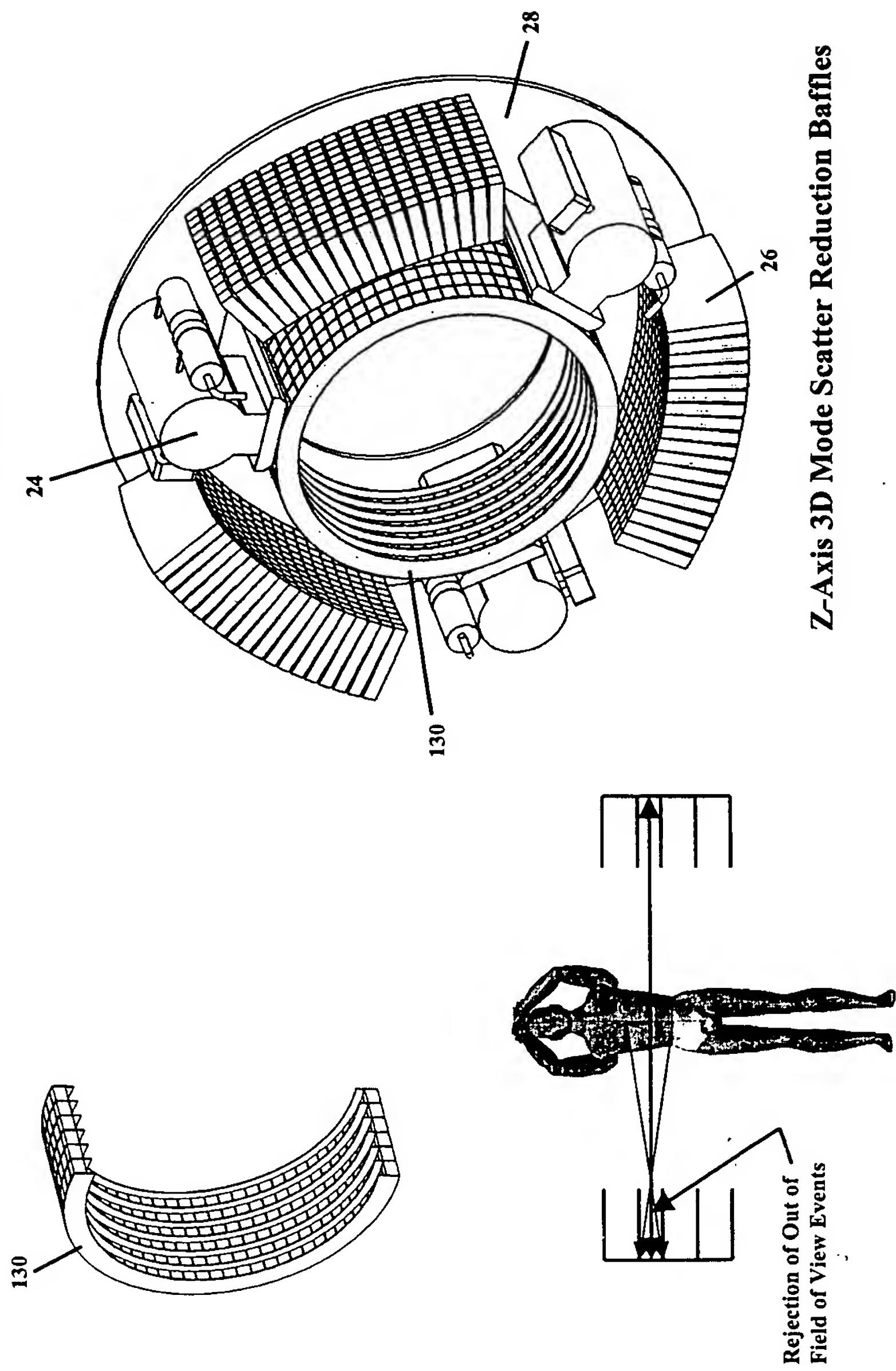
Z-Axis 3D Mode Scatter Reduction Baffles

Rejection of Out of
Field of View Events

Figure 14

System With Cone Beam Focused NM/SPECT Collimation

22

20

24

30

28

26

98
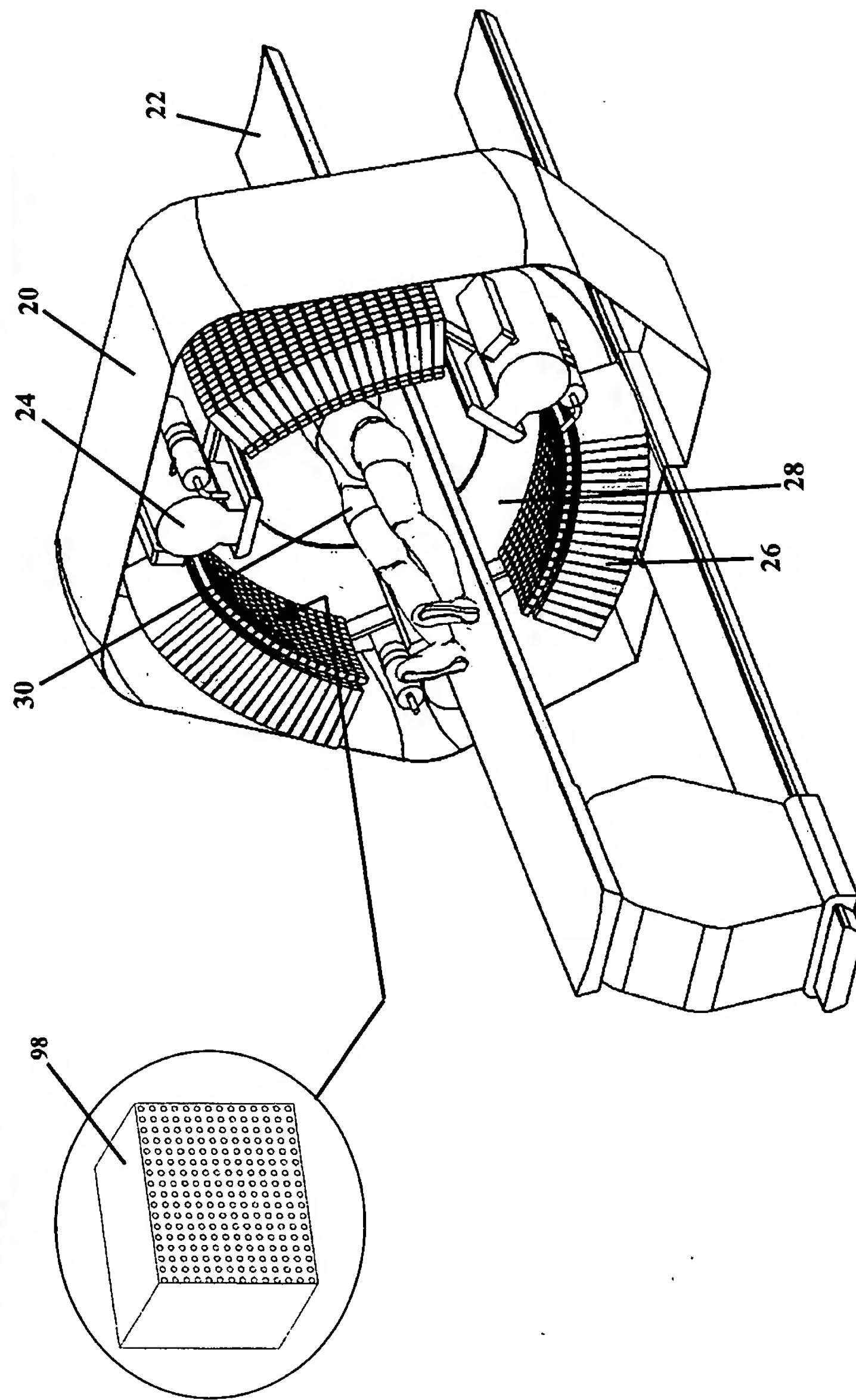
Figure 15

NM/SPECT Mode with Collimation Ring

Collimator Apertures
and SEPTA

98

98

20

140

26
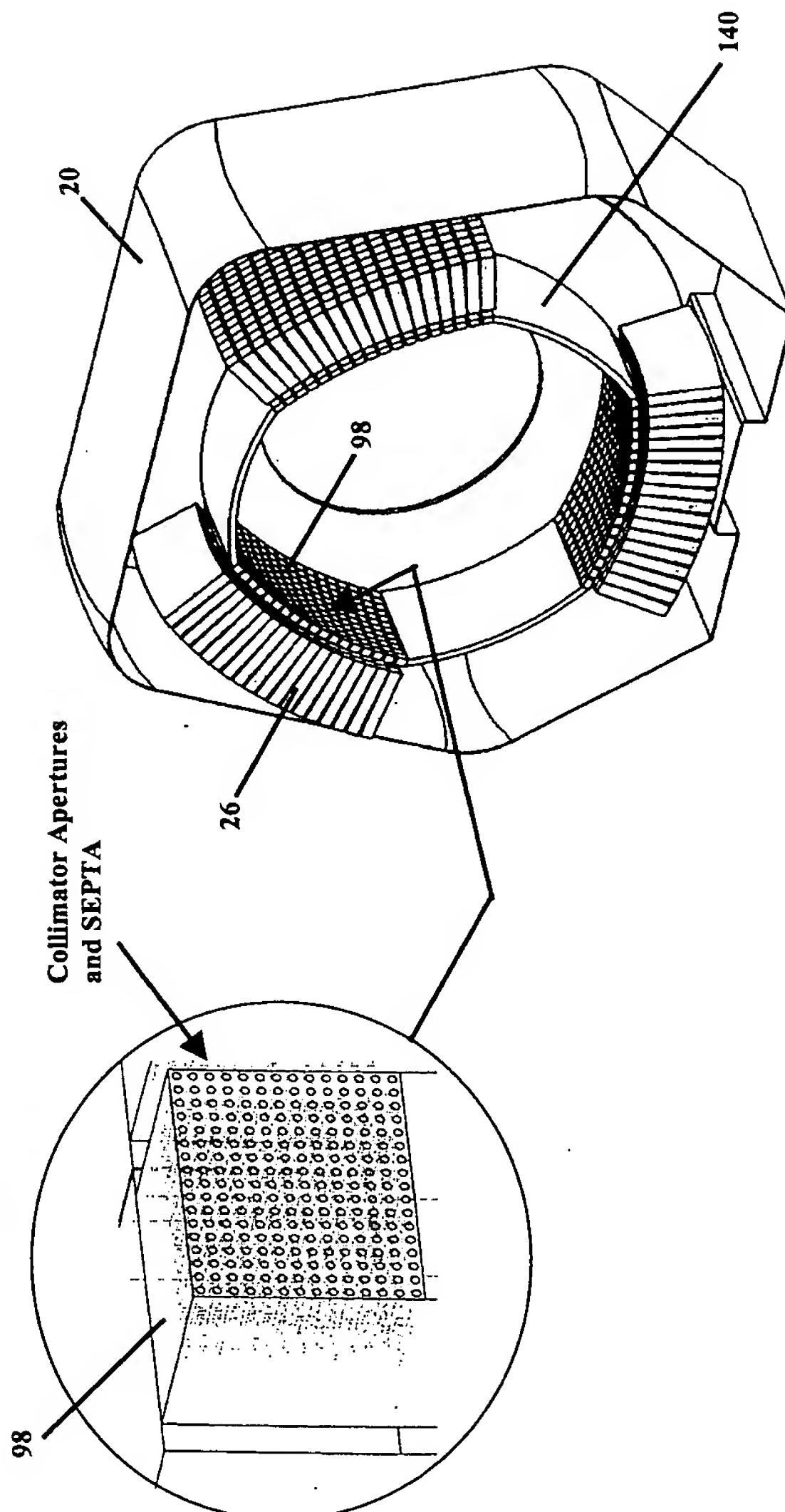
Figure 16

Cone Beam NM/SPECT LEHR Collimation and Focused 2D Curved
Detector Array

**Cone Beam
SPECT Collimation**
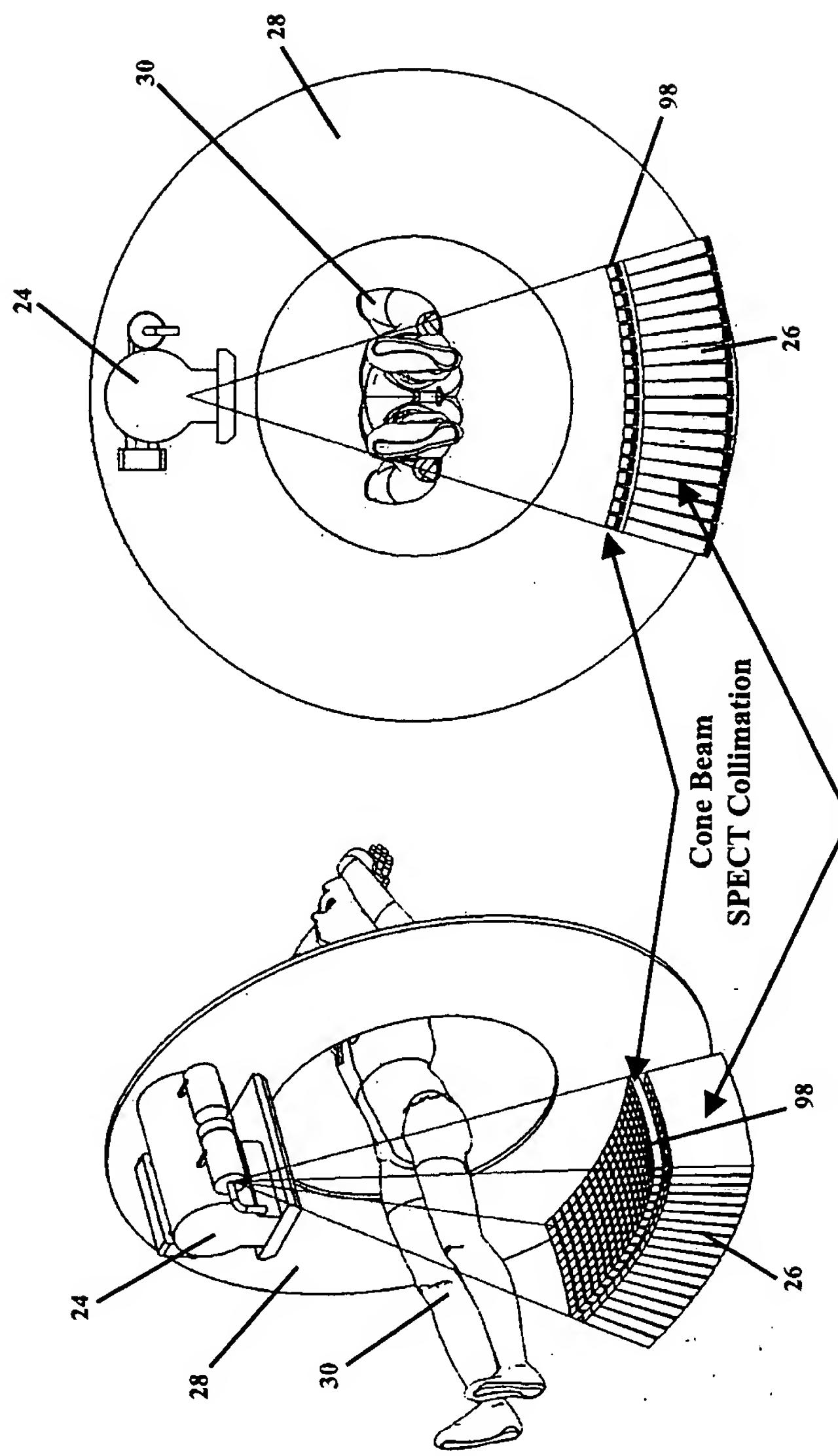
X-ray Gamma Ray Area Detector. [XGA] Detector Which
is Focused at Point Where X-ray Focal Spot is.

Figure 17

Multi-Isotope Scanning
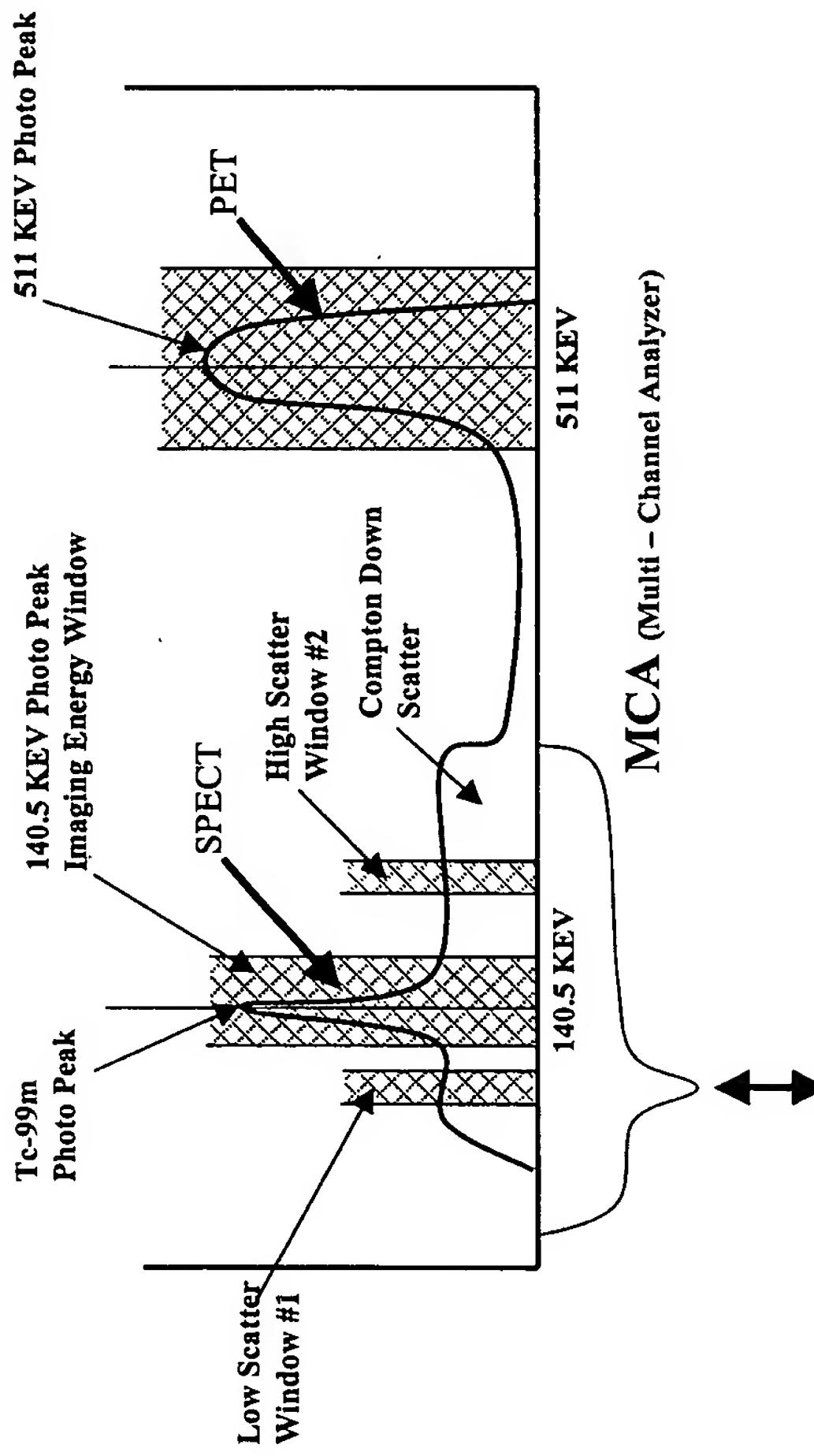
Figure 18

X-Ray Detector Scatter Rejection with Focused 2D Curved Collimation

26

Scatter
Rejection of
2D Focused
Curved Detector
Collimation

92

Rejection of
Scatter Signal

90

92

Patient

Scatter
Signal

Direct
Signal

X-Ray

24

Also used for NM Gamma and SPECT Collimation

D

L

Acceptance Angle (α) = $\tan^{-1}$ (D/L)
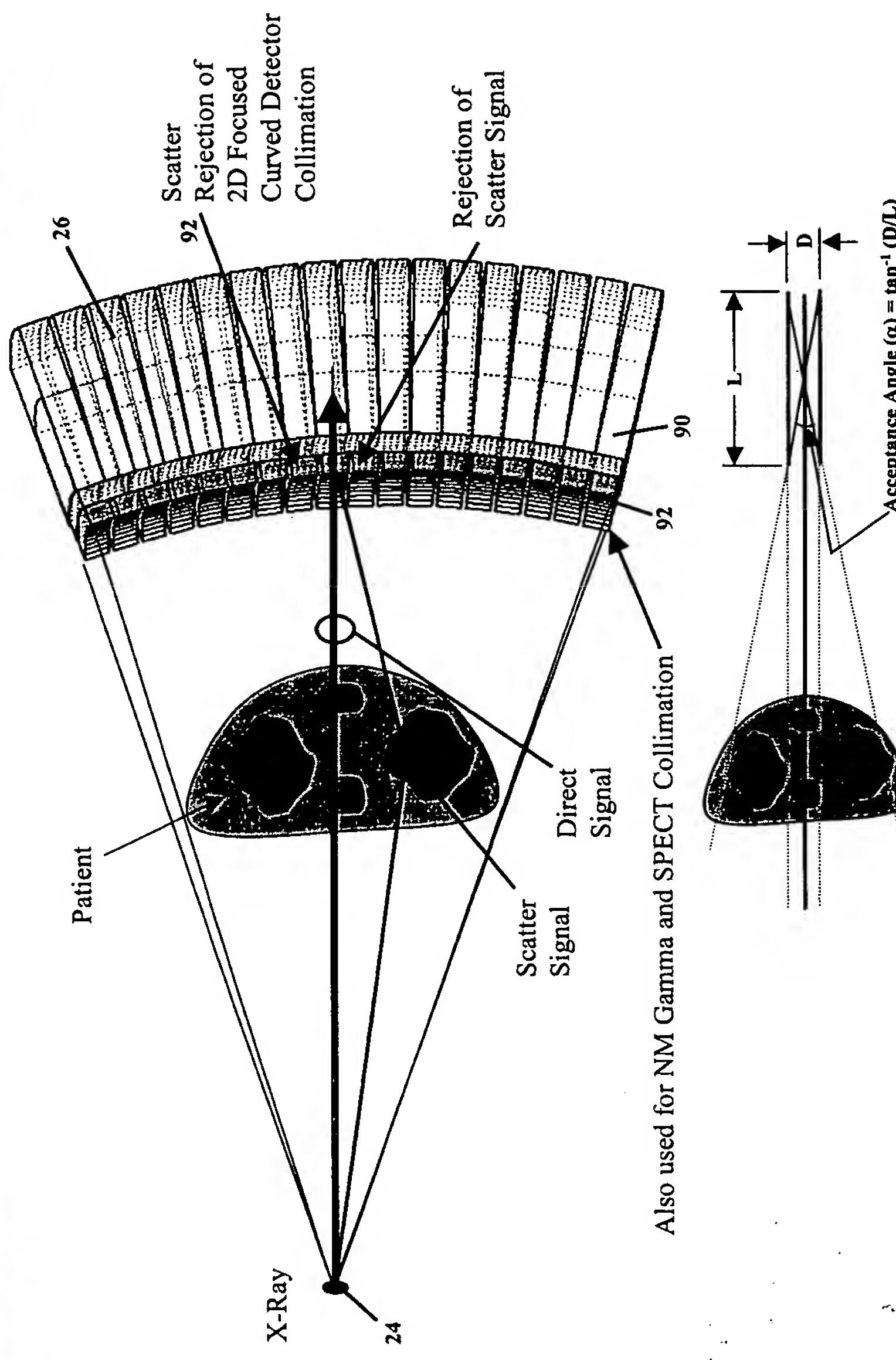
Figure 19

Sequencing of X-ray Sources for Adaptive Scatter Correction

Scatter Signature From each View or
Sub Sampled Views

Focused 2D
Curved Detector #3

X-Ray #2

Focused 2D Curved
Detector #1

Scatter

X-Ray #1

24

Focused 2D
Curved Detector #2

26

Scatter

X-Ray #3

2D Scatter Profile

Scatter Intensity

Rotational Angle θ

0°

360°
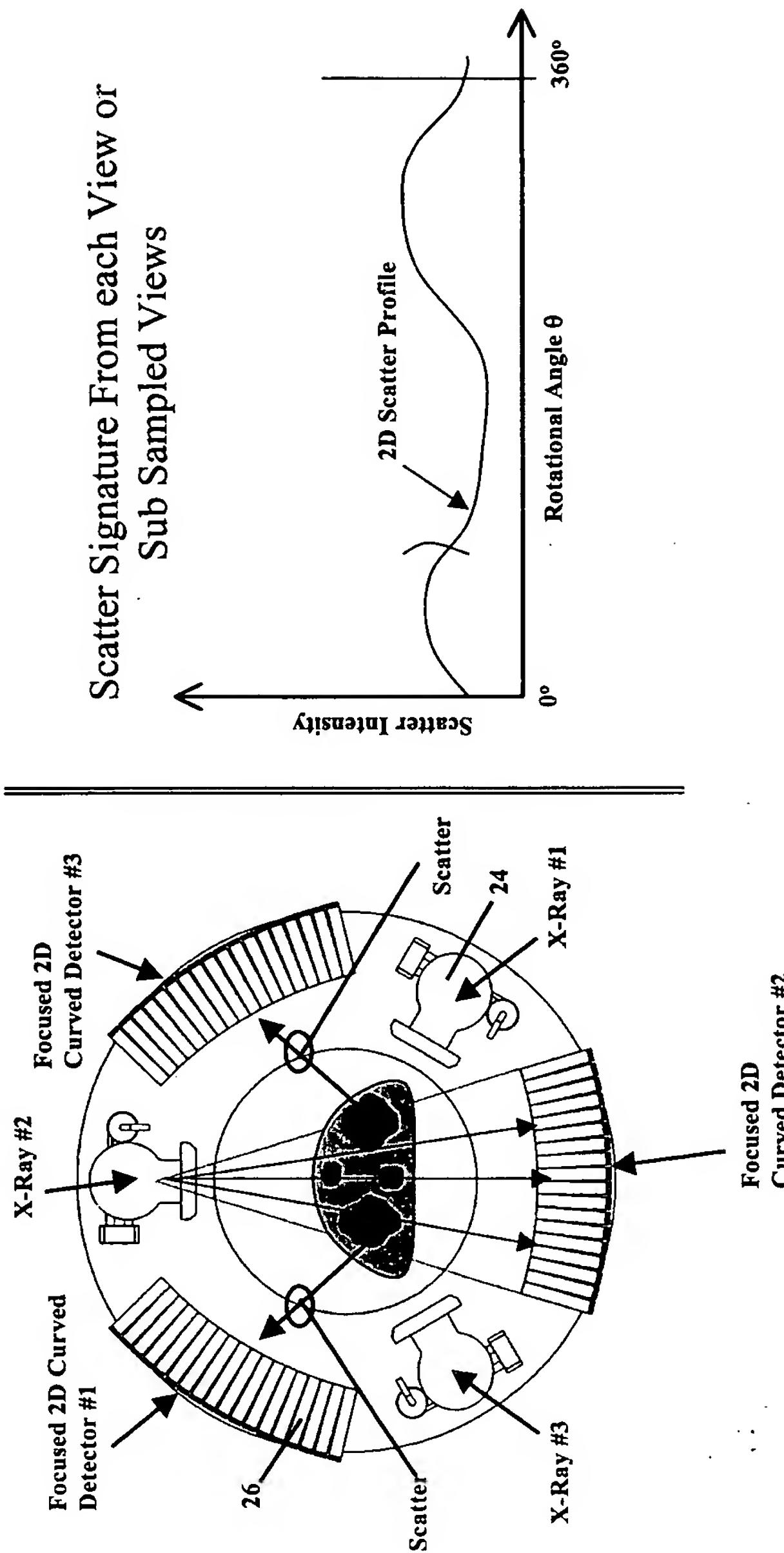
Figure 20

Modulation and Demodulation for Scatter Correction with Multiple Sources

Modulation F #1

Grid Modulation

Detector #2

X-Ray #1

24

Detector #3

Modulation F #2

Grid Modulation

X-Ray #2

Scattered Signal from #2

Modulation F #3

Grid Modulation

X-Ray #3

Scattered Signal From #3

Scattered Signal from #2

26

Direct Signal

Detector #1

PreAmp

Direct Demod

LPF

Demodulation Signal #1

FIG. 21a

F #3

F #1

F #2
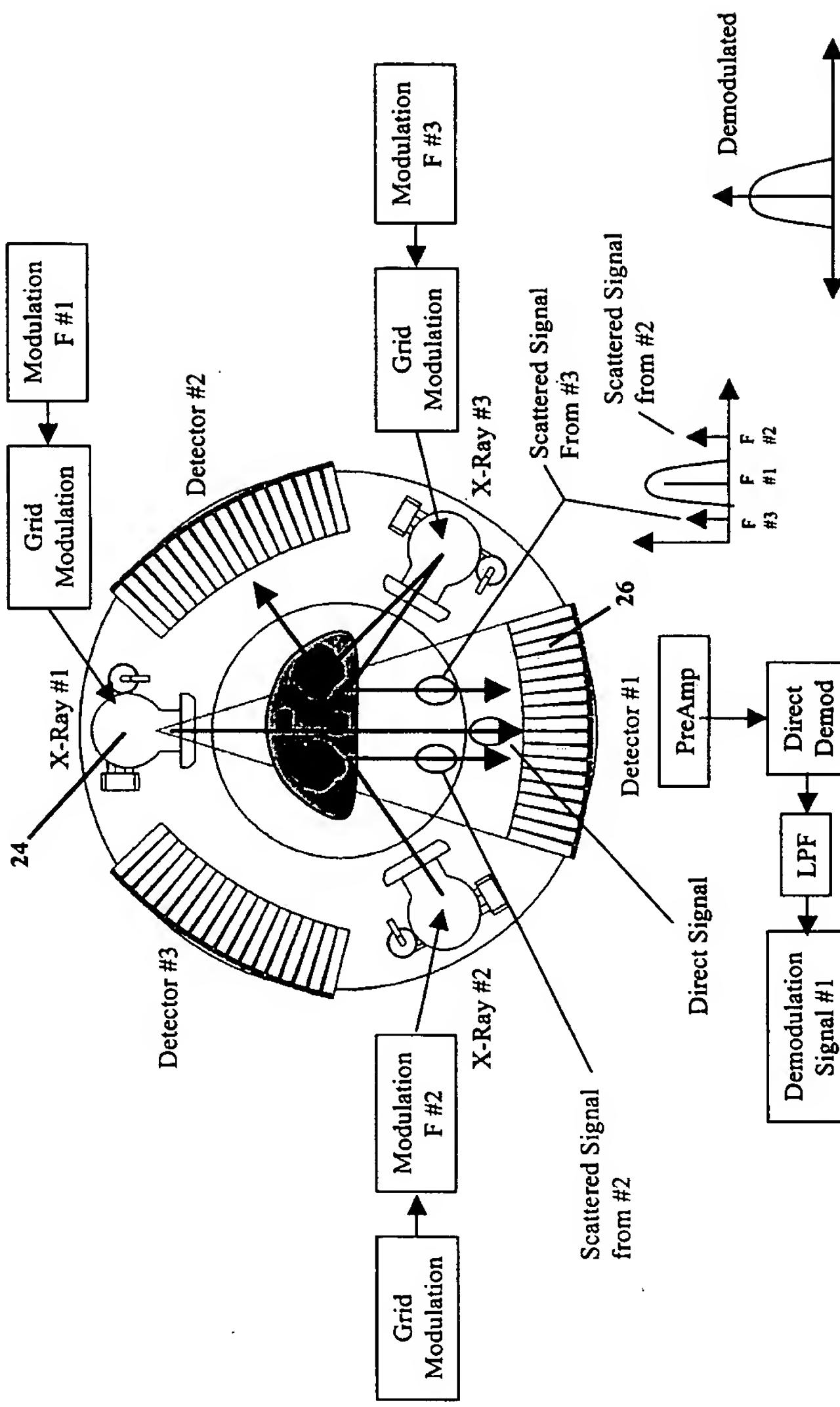
FIG. 21b

Demodulated

Demodulation Signal from Detector #1

FIG. 21c

Figure 21

System Level Diagram of Modulation and Demodulation For Multiple Sources for VCT

Master Modulation Signal F #1 — 164

Modulation Signal — 160

Grid Control — 162

Detector #2

X-Ray #3

Scattered Signal From #3

Detector #3

X-Ray #1

24

26

Detector #1

PreAmp — 168

Demodulation — 166

X-Ray #2

Scattered Signal from #2

Scattered Signal from #3

Demodulated

Demodulation Signal from Detector #1

F #2

F #1

F #3
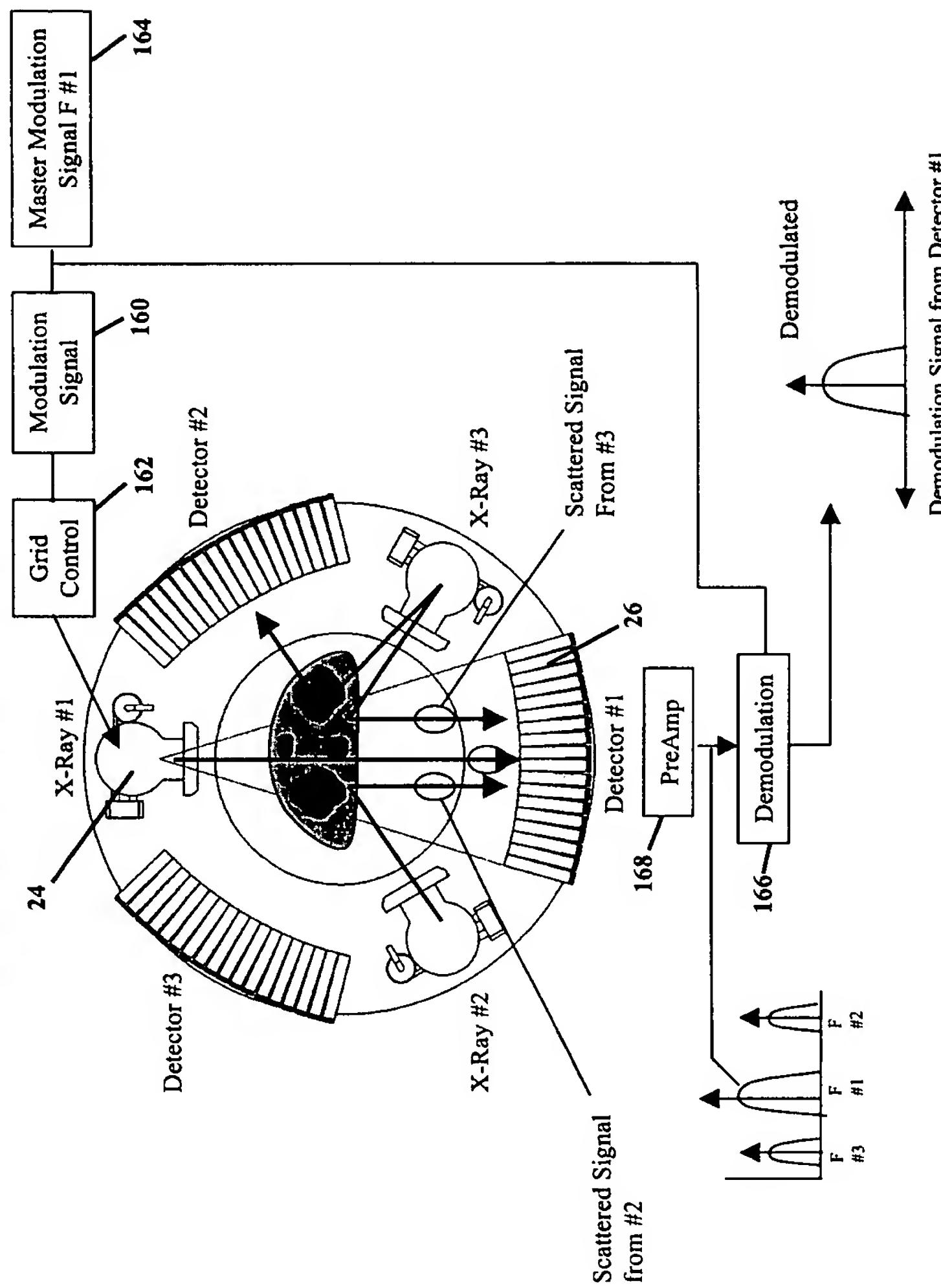
Figure 22

Step and Shoot VCT Imaging

Figure 23

X-ray Focal Spot

Scan 1
Scan 2
Scan 3
Scan 4
Scan 5
Scan 6
Scan 7
Scan 8

26

26

Multiple 360 degree Rotations Stepping Down the "Z-axis"

Z -Axis
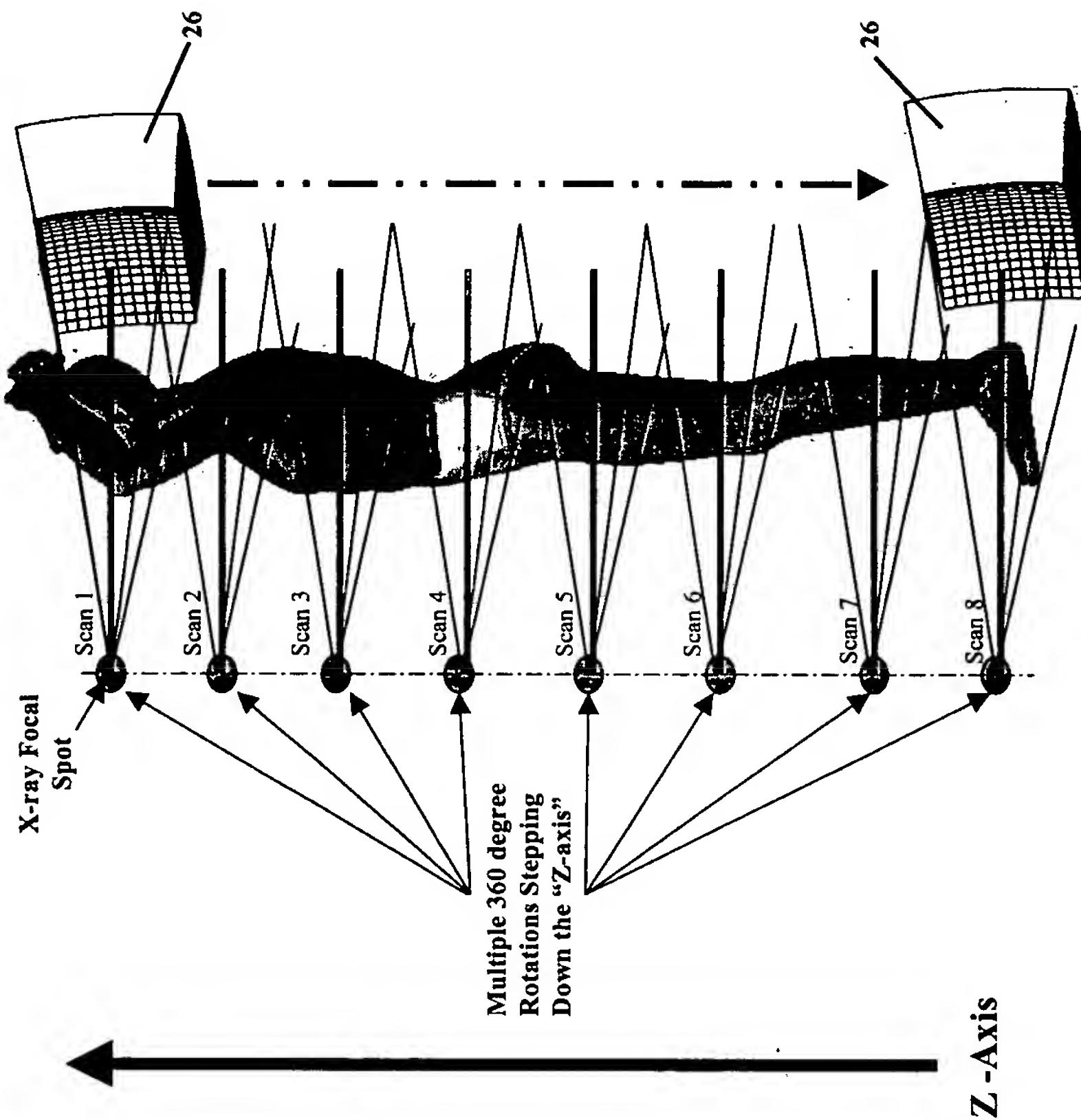
Spiral 3D X-Ray, DAQ and VCT for Cone Beam Reconstruction

FIG. 24a

Spiral Path with Traverse and Pitch
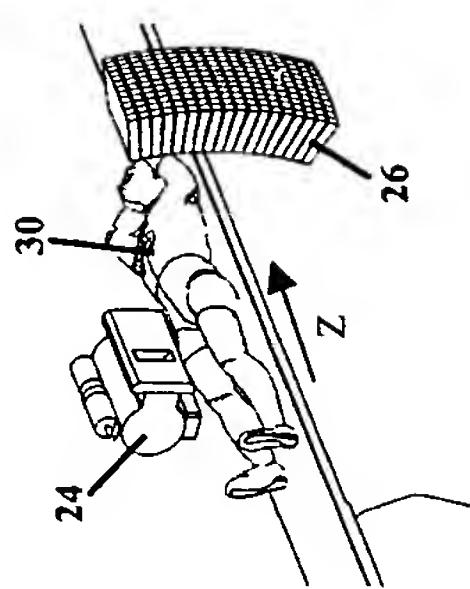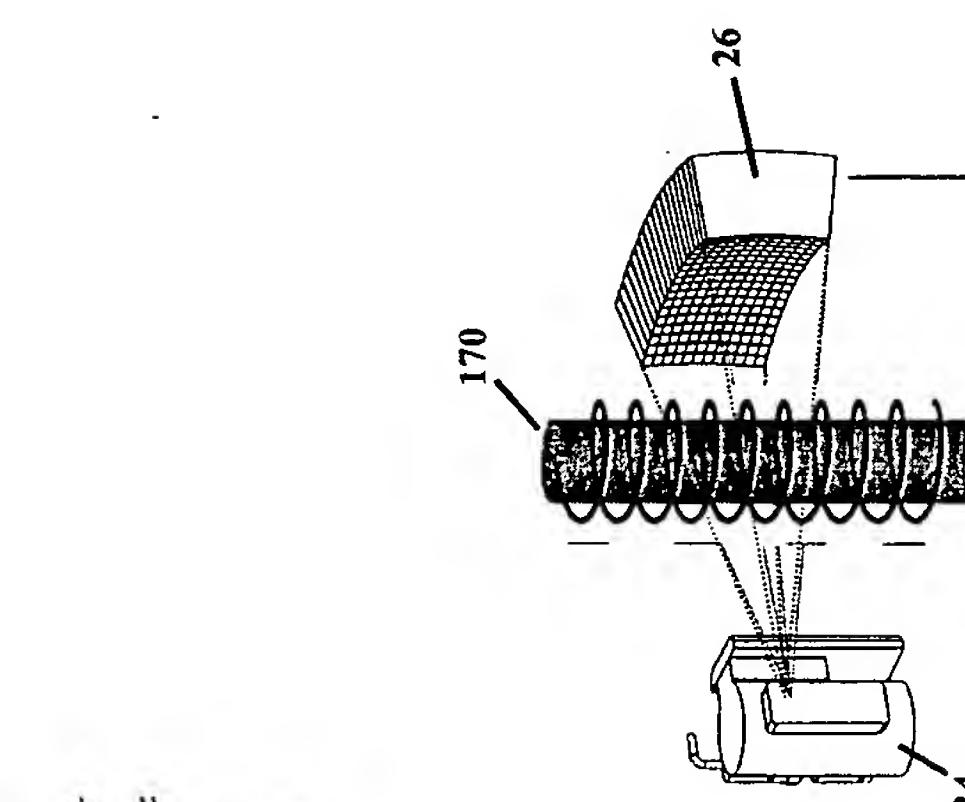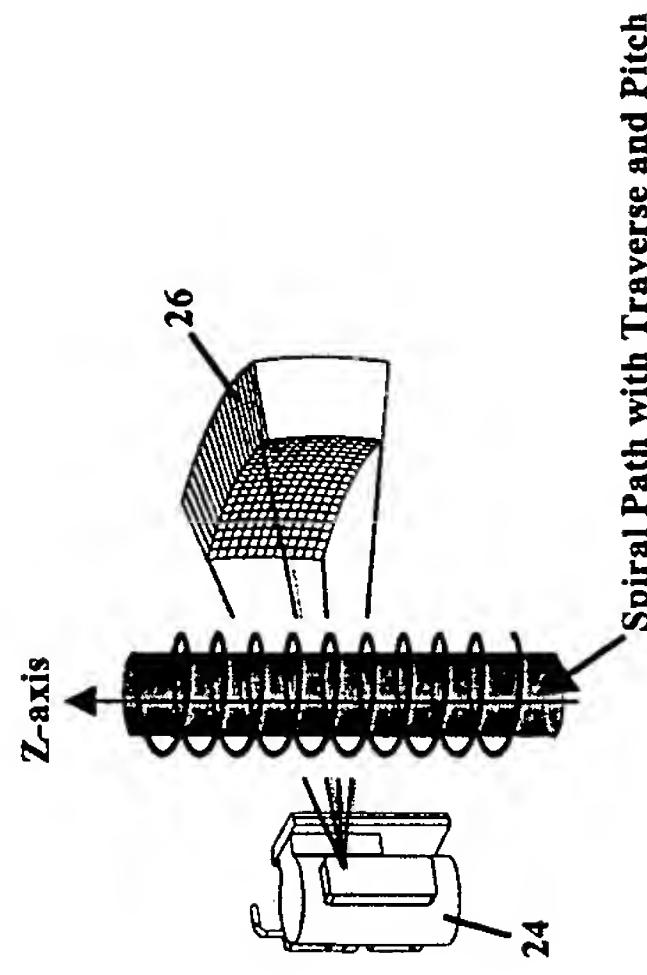
FIG. 24b

FIG. 24c

Figure 24

Spiral VCT with Multiple Heads

Detector

Virtual Detector

H_v

W_v

H_r

W_r

172

Source Point

Detector Projection to Scan Center

FIG. 25c

Redundant or Unused Data for 3D Recon

Desired Data for 3D Recon

Redundant or unused Data for 3D Recon

172
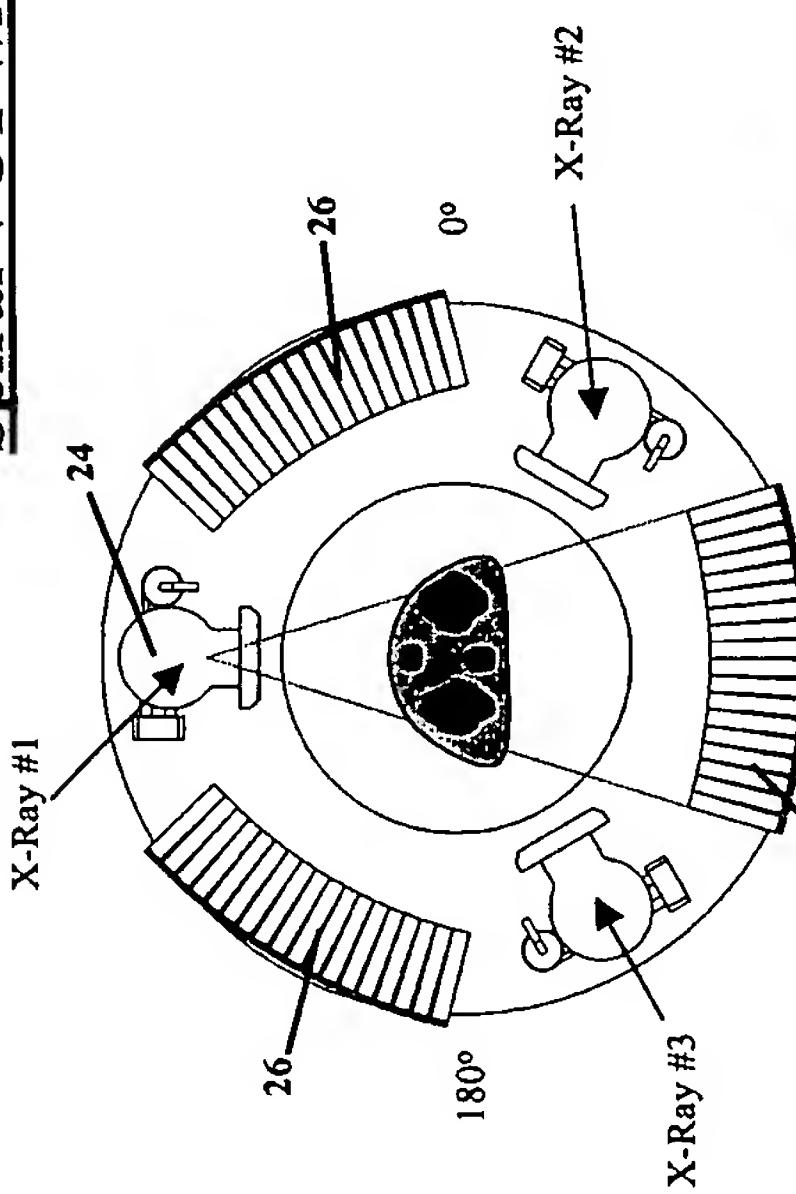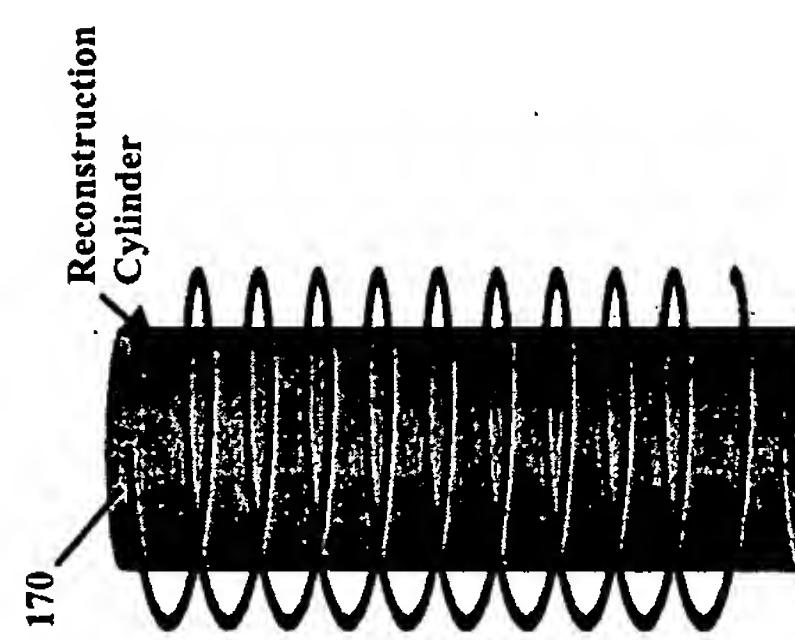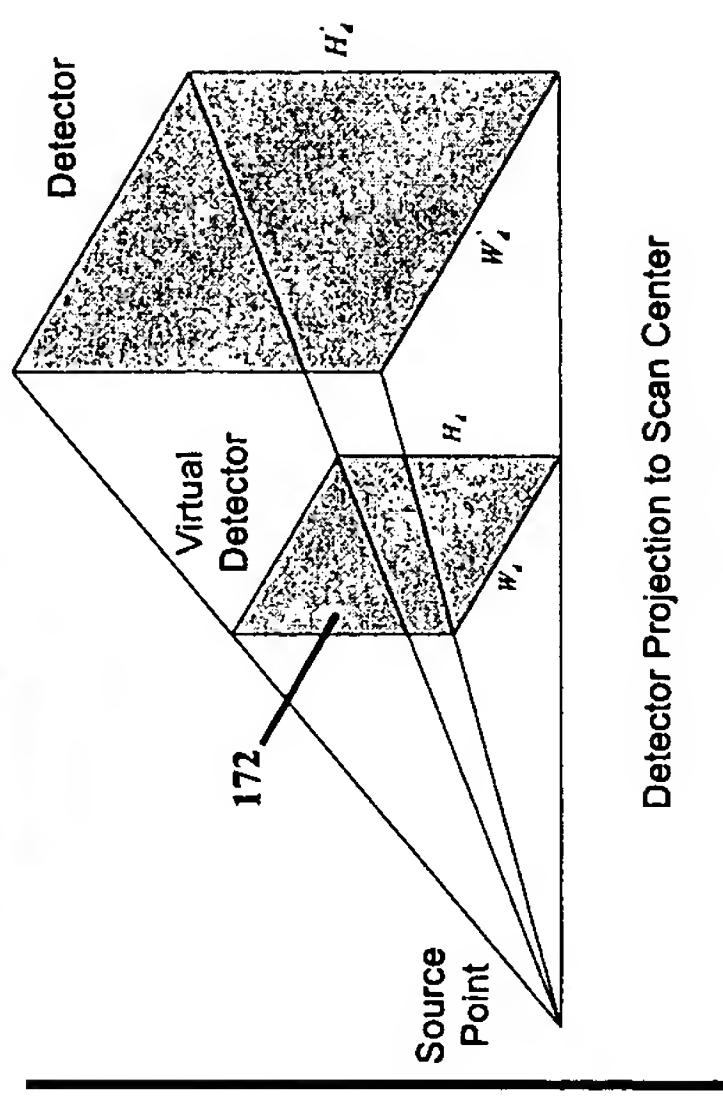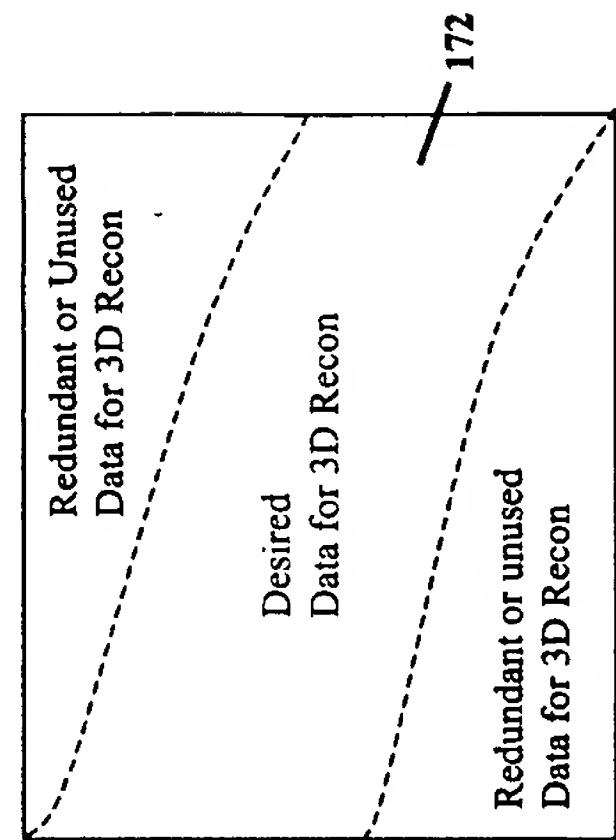
Virtual Detector Sampling Region

FIG. 25d

Reconstruction Cylinder

170

26

0°

X-Ray #2

24

X-Ray #1

180°

X-Ray #3

26

26

FIG. 25a

Head 3

Head 2

Head 1

Spiral Path with 3 Heads with respective Central Rays on Reconstruction Cylinder

FIG. 25b

Figure 25

Cone Beam Slant Source Collimation for Spiral VCT Imaging

X-ray Focal Spot

Slant Spiral Collimator Aperture

Slant Spiral Collimator

Slant Cone Beam for Spiral Scanning

Redundant Data for 3D Recon

Desired Data Boundary

Cone Beam Slant Source Collimation Rejection Regions

Desired Data for 3D Recon

Redundant Data for 3D Recon
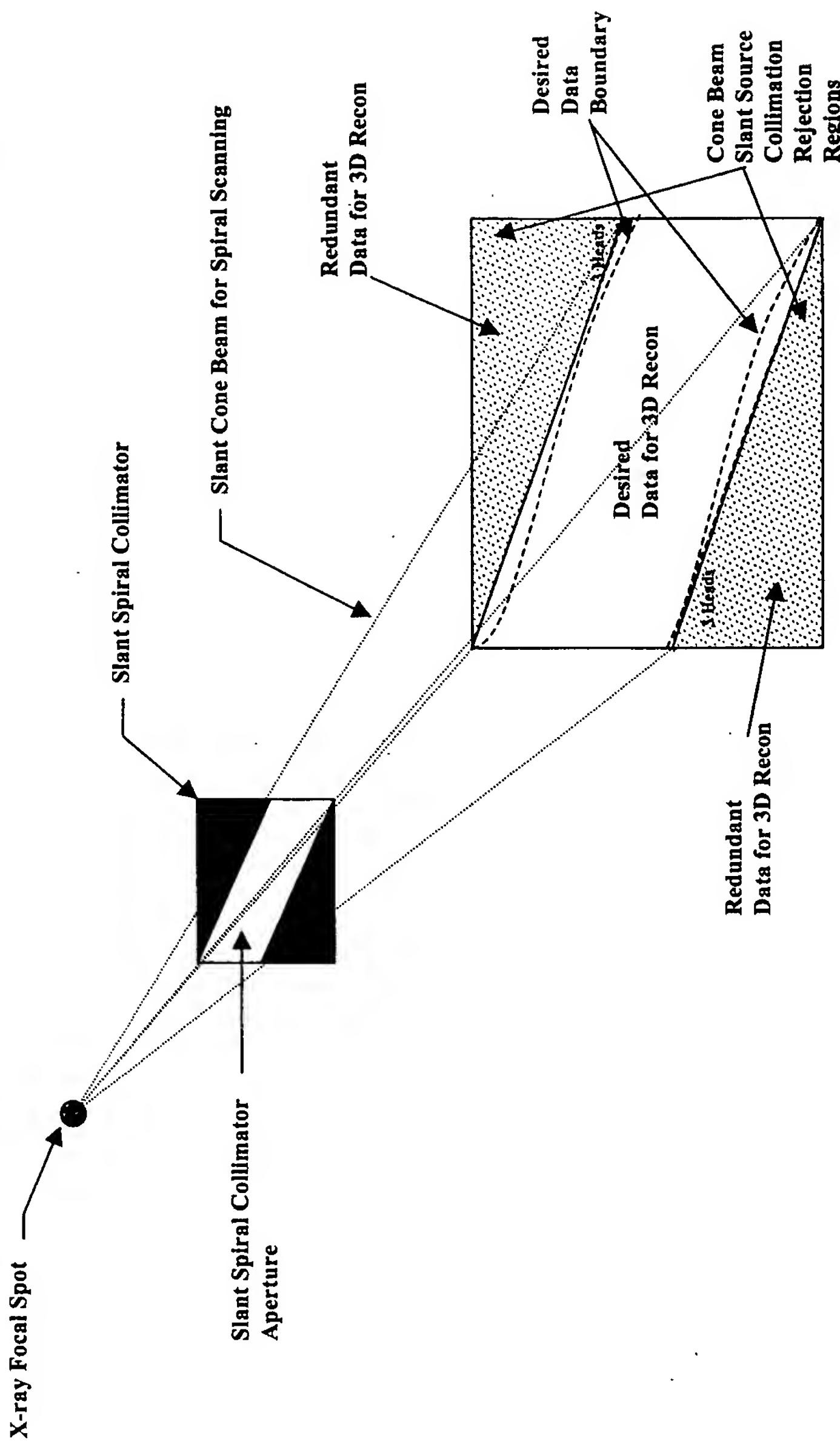
Figure 26

Multi-Plane Planning System Imaging

Rotate Plate Rotating and Snap Shot Planning Views Taken While Traversing Patient

24

26

(0,0) Anterior 0 L R

(0,0) Right 90 Post Ant

(0,0) Post 180 R L

(0,0) Left 270 Ant Post

Virtual Plane 0° (0,0)

VP @ 90° (0,0)

VP @ 180° (0,0)

VP @ 270° (0,0)

Patient

Ant R L Post
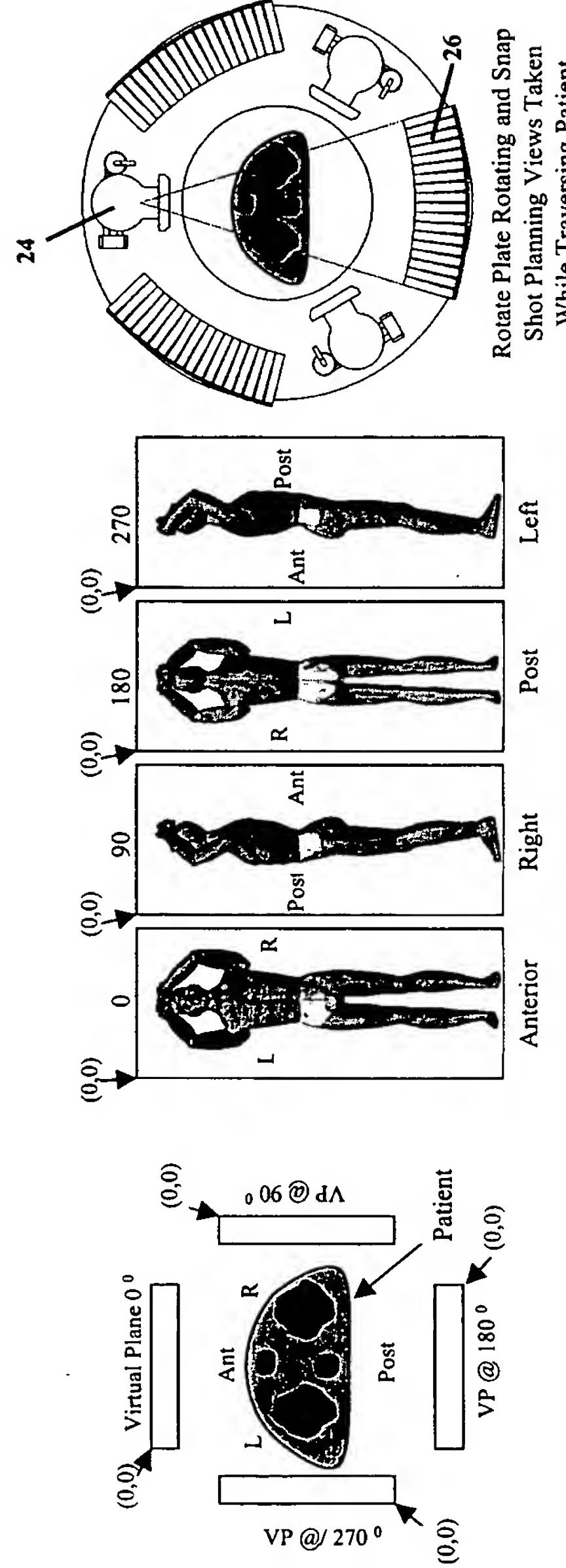
Figure 27

Whole Body Dose Control From Planning System
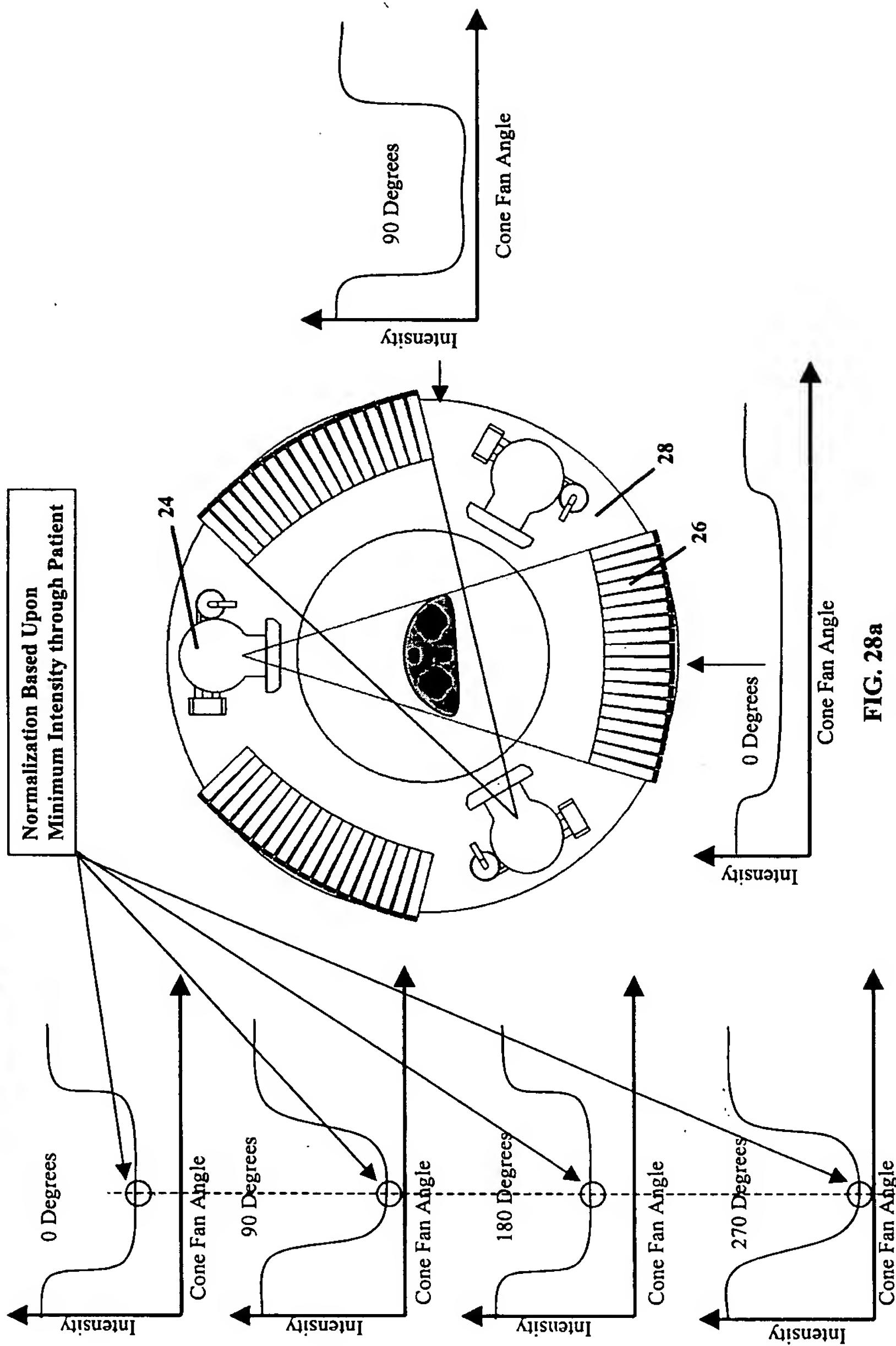
Normalization Based Upon Minimum Intensity through Patient

FIG. 28a

FIG. 28b

Figure 28

Dynamic Timing Control

Protocol of Scan Procedure

Power Contrast Injector

Foot Exposure Contrast

Monitor of contrast Levels for
Triggering of Image Acquisition.

46 — Dynamic Timing Control System

48 — Gating Control System

52 — X-Ray Control

50 — DAQ

54 — Motion Control System
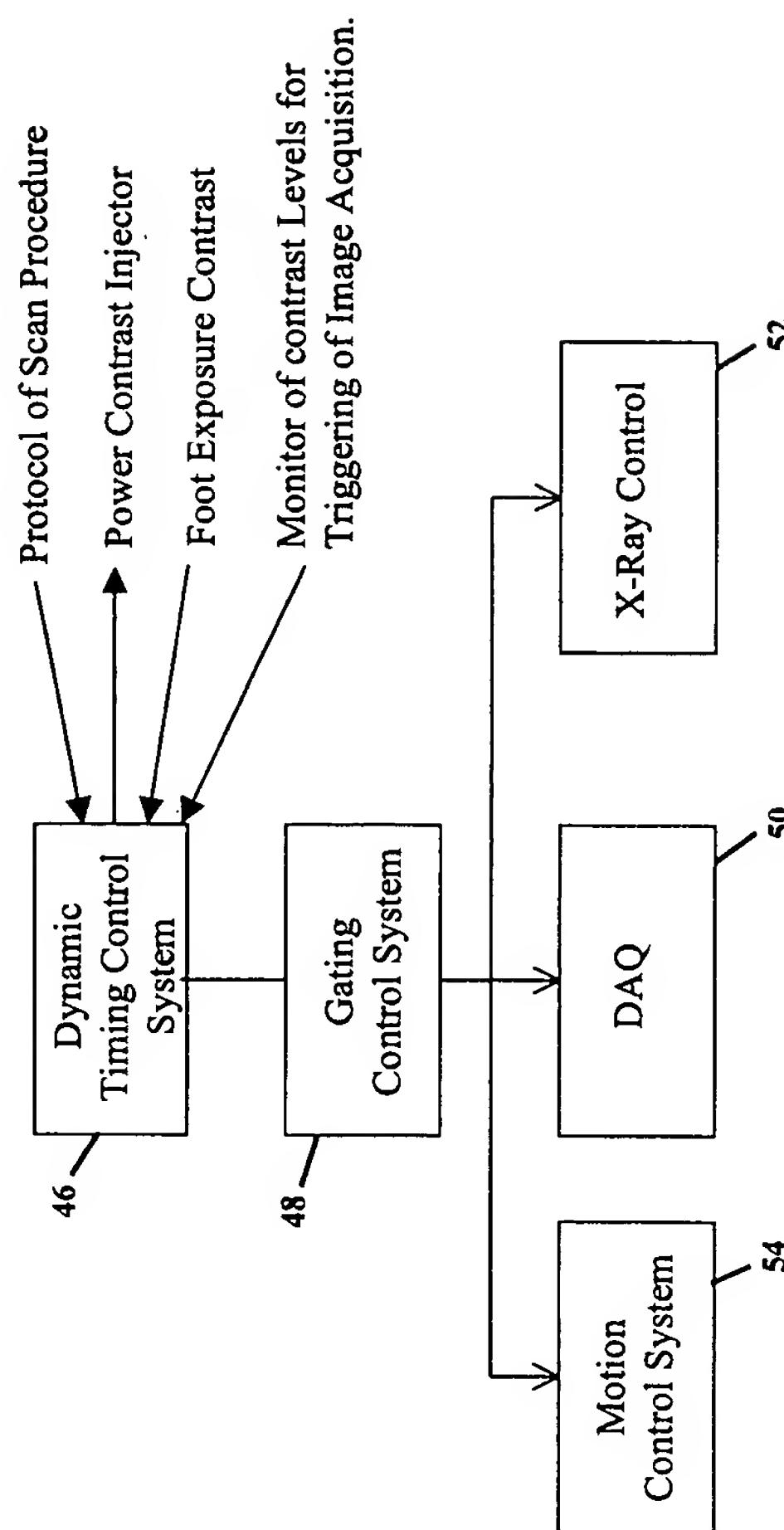
Figure 29

Retrospective Gated Imaging System
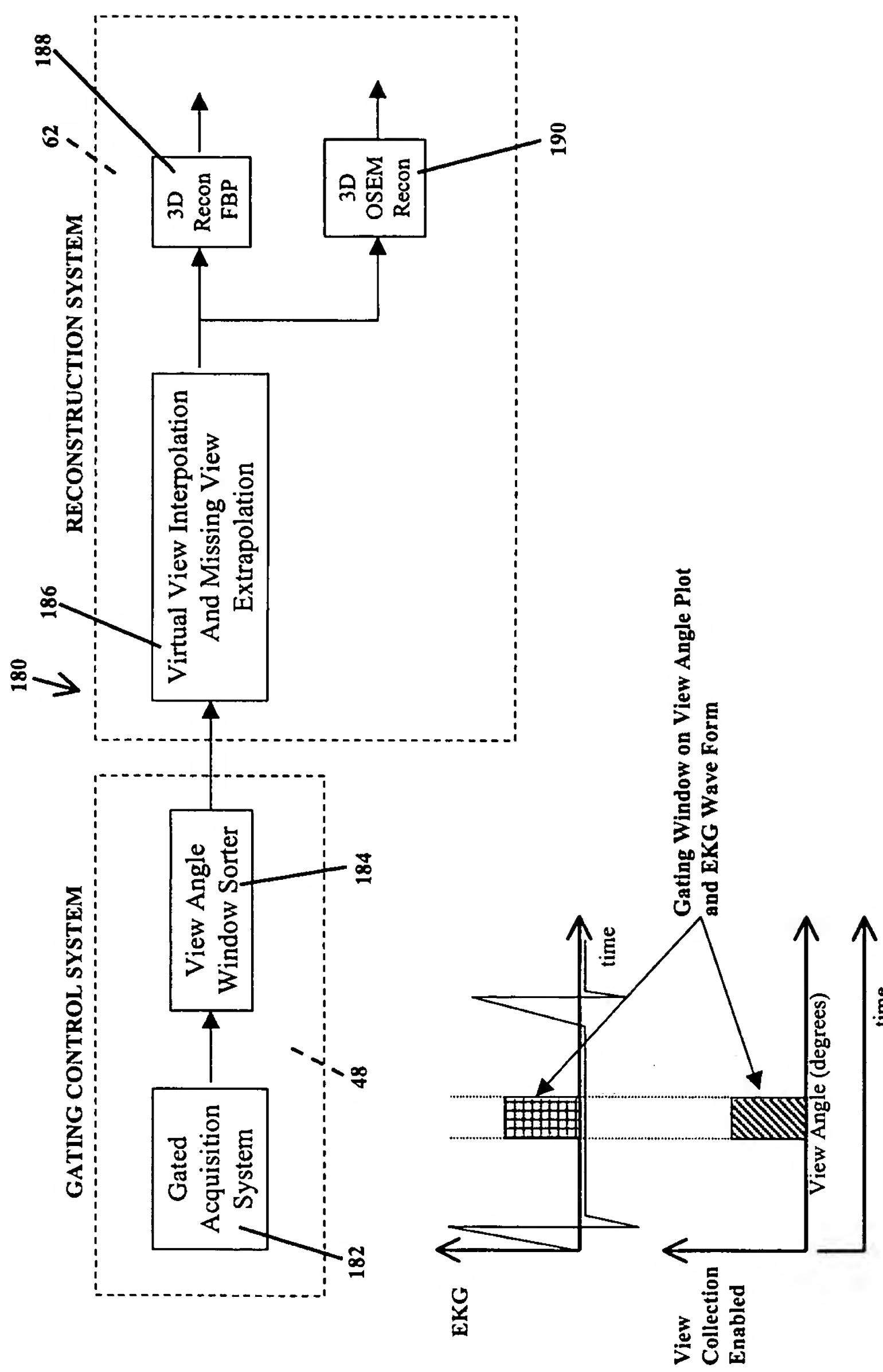
Figure 30
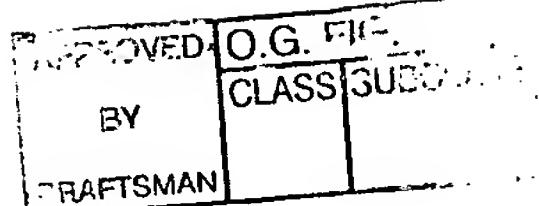
Prospective Gating Control System with Cardiac EKG

Desired and Gating Window

Systole

Diastole

EKG

Heart Rate: 60 bpm

EKG

Physiological Breath Hold Gate Physiological Respiratory

Gating Algorithm

Historical Gating Control Information

Operator Go command or Remote Foot Switch

Gating Control

48

X-ray on Control

Detector Sampling Control

Rotor Speed

Rotor Position

Traverse Speed

Traverse Position
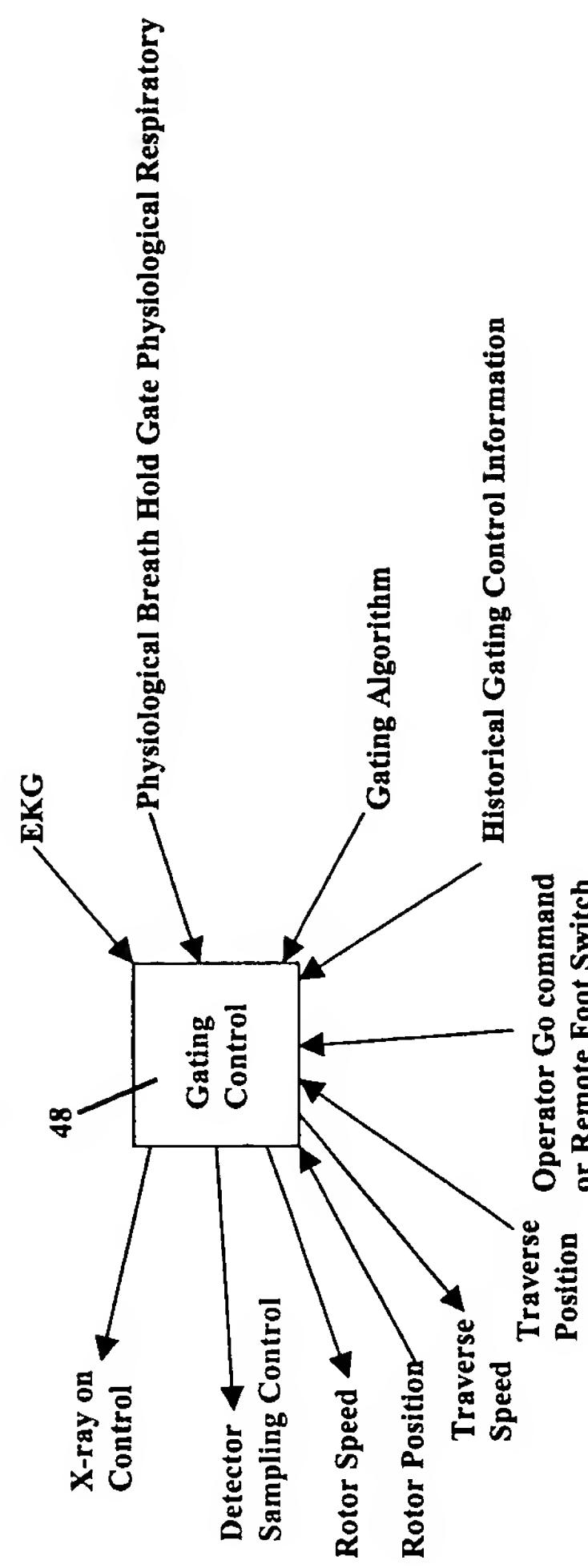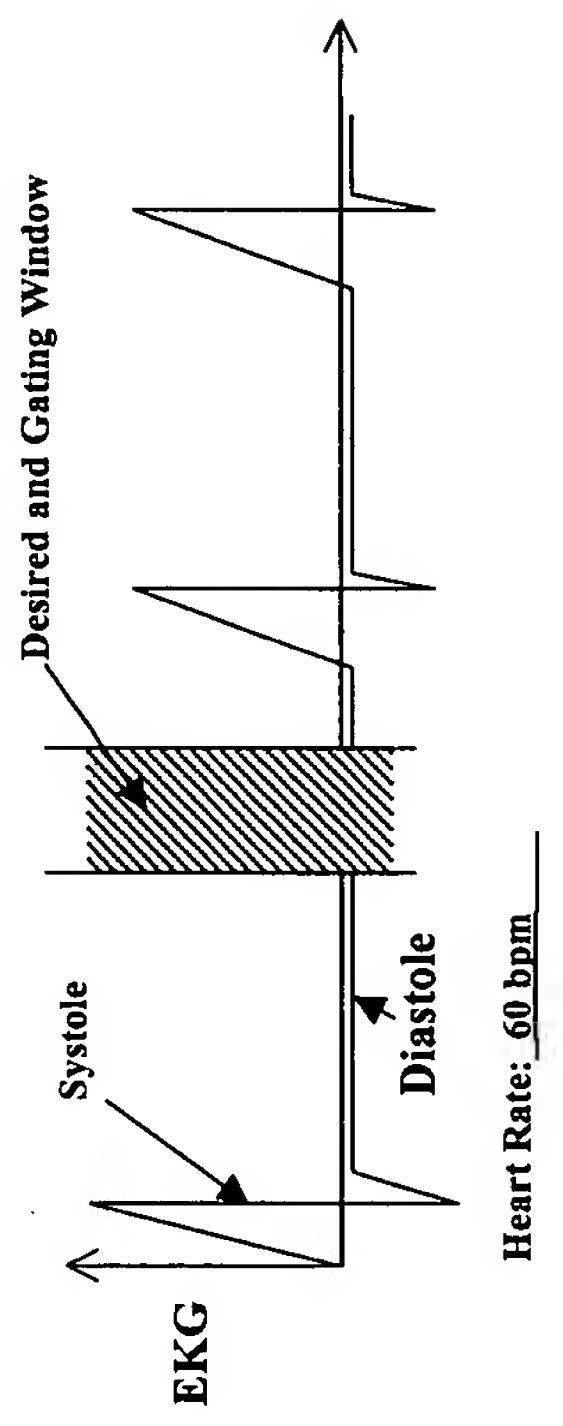
Figure 31

Prospective and Retrospective Gated DAQ and Reconstruction Imaging

Prospective Gating Control
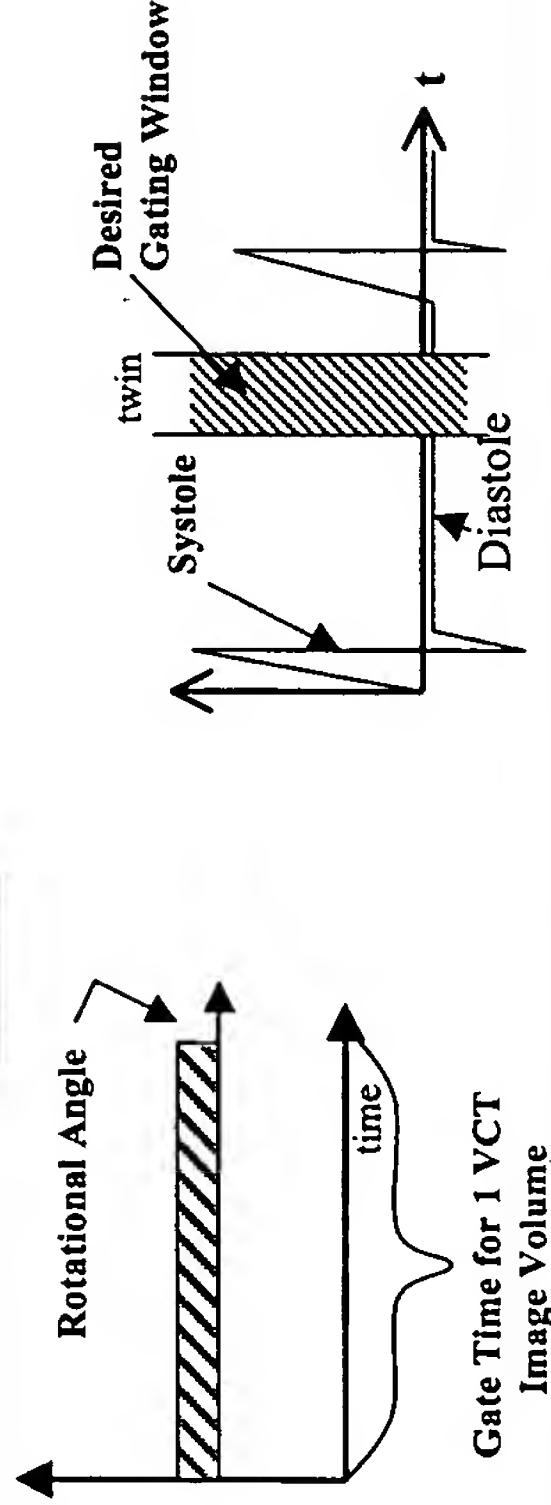
FIG. 32a

FIG. 32b

Retrospective Gating Control
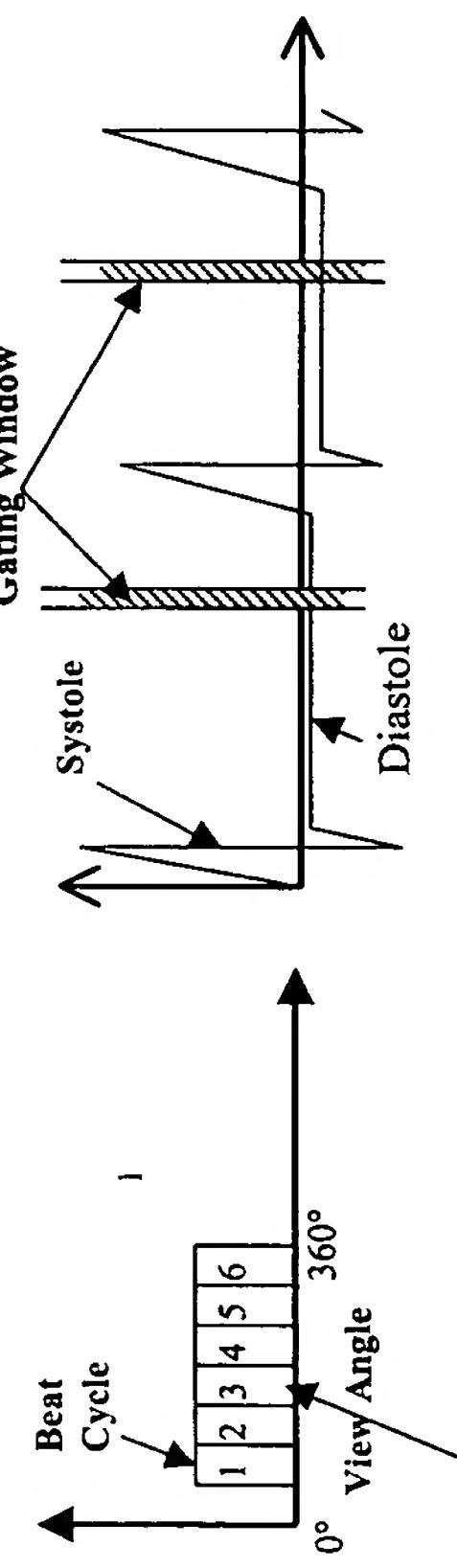
FIG. 32c

FIG. 32d

Multi Cycle – Contiguous
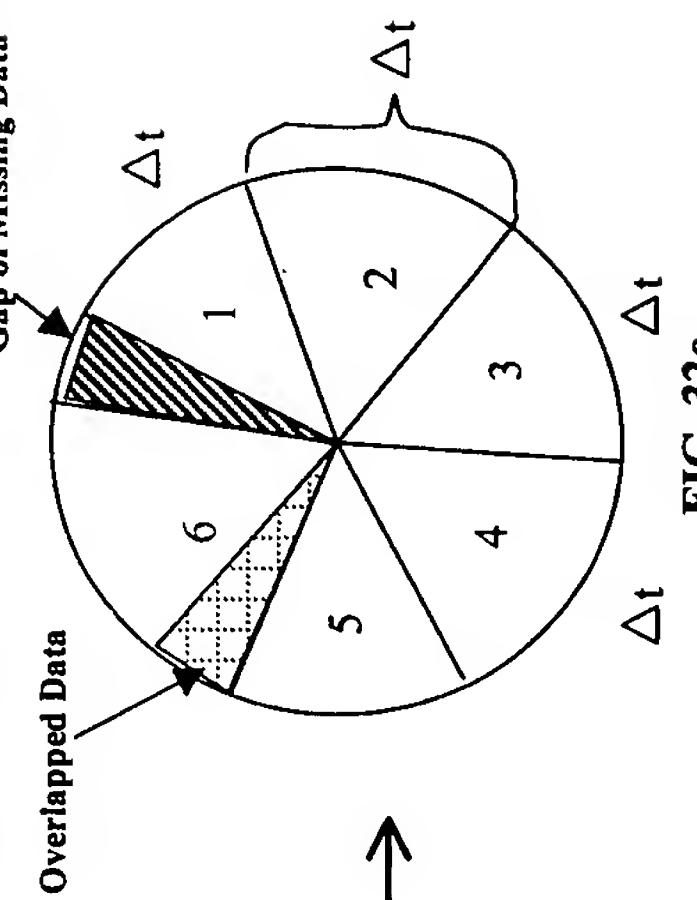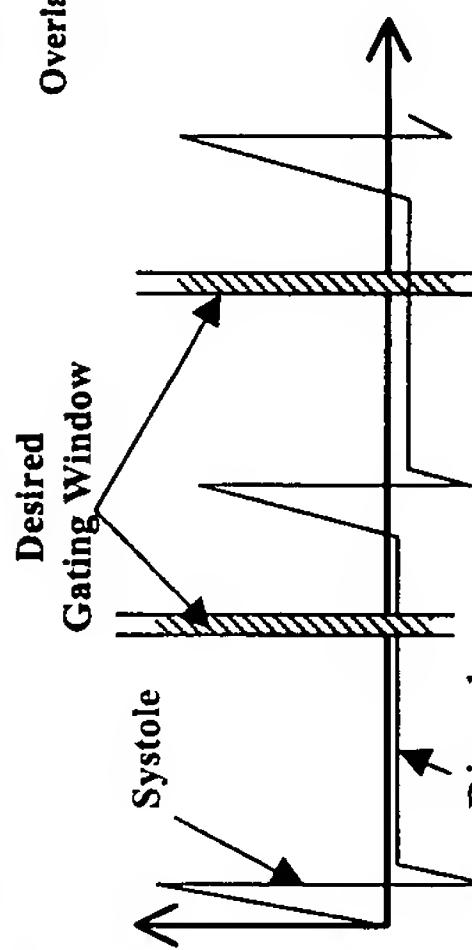
FIG. 32e

Figure 32

# Gated DAQ and Reconstruction for Retrospective Cine' Dynamic

Cardiac Imaging

Derived ~ 50ms Windows

1 2 3 4 5 6 1 2 3 4 5 6 1 2 3 4 5 6 1 2 3 4 5 6 1 2 3 4 5 6

C1 C2 C3 C4 C5

FIG. 33a

Views or θ/sec = 360 ° / .25 = 1440 °/sec
½ ° View Spacing = 2880 views/sec

Desired Window: 50ms
In One Window: 2880 x 5 x 10 $^{-2}$ = 144 views
72 degrees

3 cycles for 180 °   3 x 72 = 216°
5 cycles for 360 °

5 Sectors of Pie Diagram

Average EKG

FIG. 33c

Z axis

R

| 1 | 2 | 3 | 4 | 5 | 6 |

0° View Angle (θ) 360°
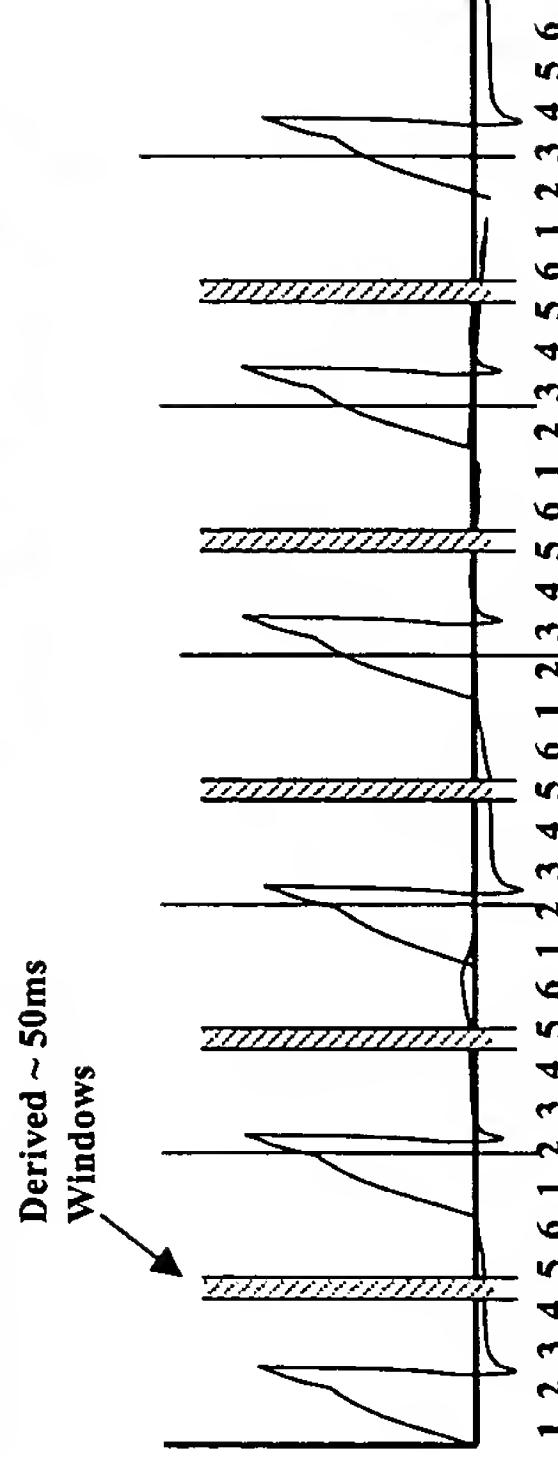
FIG. 33b
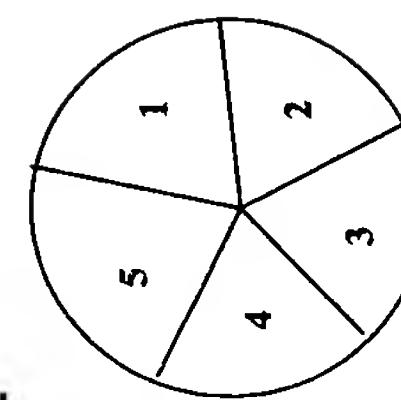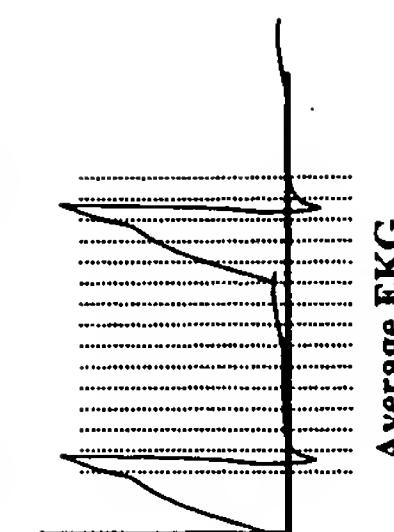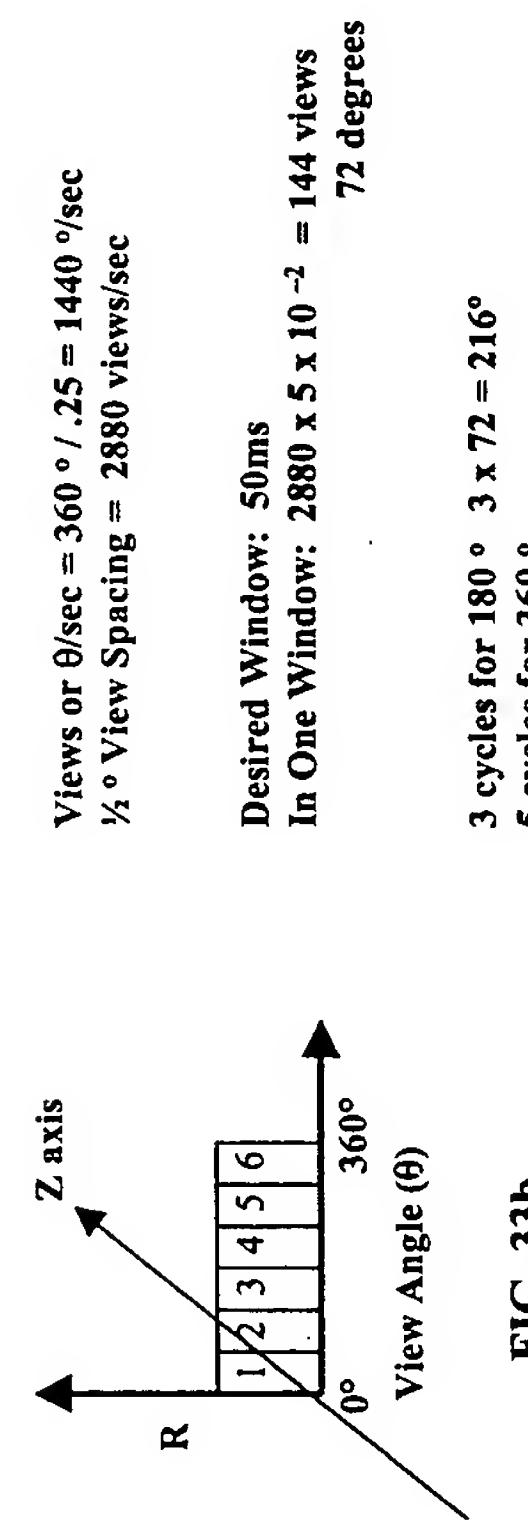
Figure 33

PET Transmission, Attenuation & Scatter Correction

VCT Attenuation MAP

Transmission Attenuation
Map at 511 KEV Energy Level from VCT Images

PET Attenuation Correction
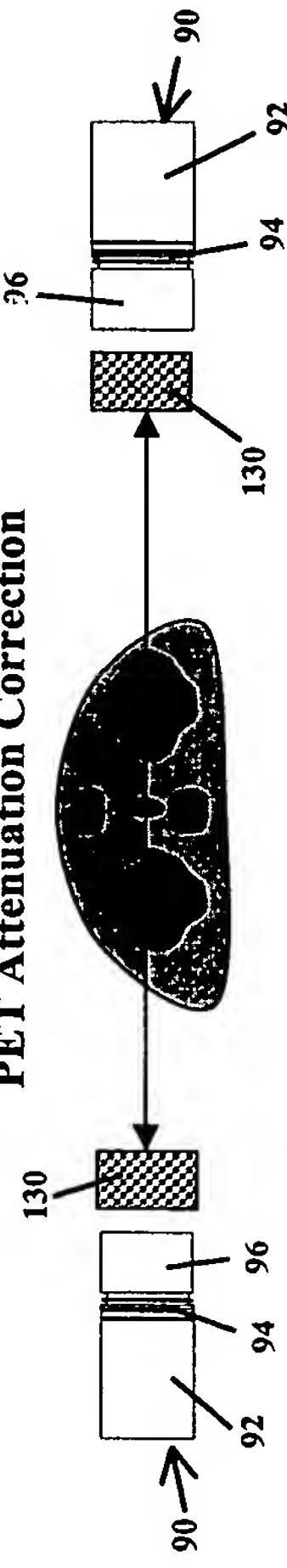
Correction Map for PET New Corrected PET
Projections for OSEM Recon.

PET Scatter Correction

Scatter

LOR
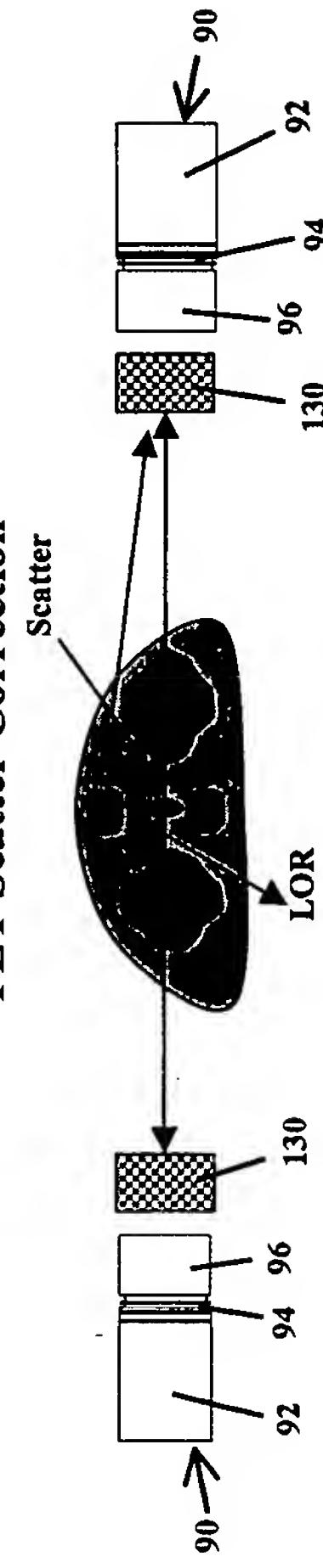
Scatter Correction from VCT Images and
Count Rates on a Projection View Basis

Figure 34

NM/SPECT Transmission, Attenuation & Scatter Correction

## VCT Attenuation MAP

Transmission Attenuation
Map at NM/SPECT Energy Levels from VCT Images

NM/SPECT Attenuation Correction
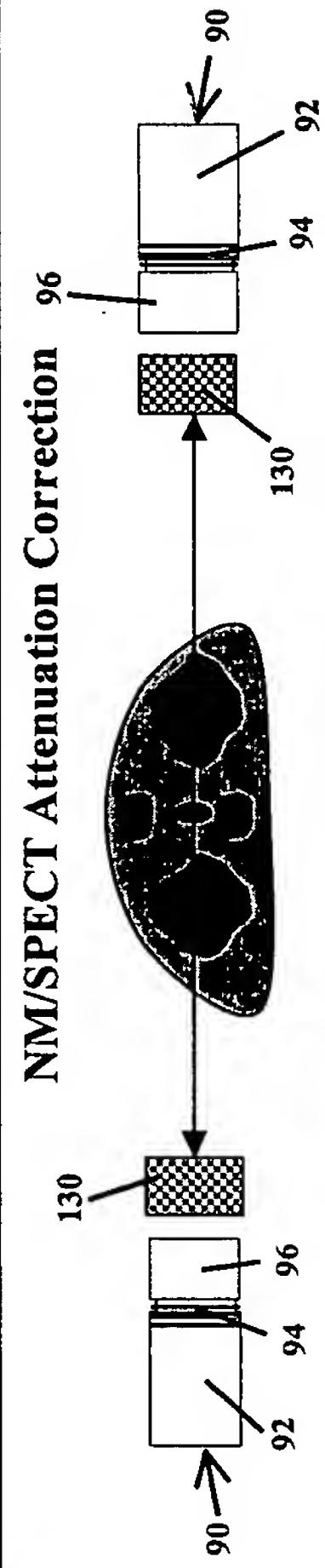
Correction Map for NM/SPECT New Corrected
SPECT Projections for OSEM Recon.

Scatter Correction

Scatter Correction from VCT Images and
Count Rates on a Projection View Basis
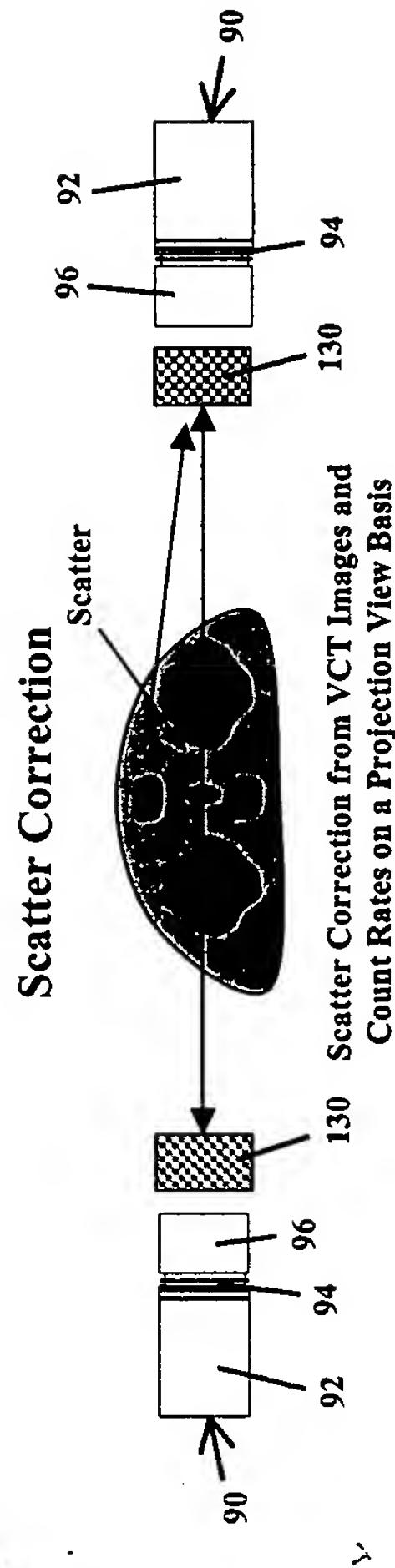
Figure 35

# Patient Fused Multi-Modality Imaging and Analysis System

IMAGE ANALYSIS SYSTEM

Computer Aided Diagnosis

Fusion

Metabolic and Morphological Info

Disease Process Model

Anatomy Image

PET Function FDG

SPECT Function

Gold History Data Base

16

MULTI MODELITY IMAGING SYSTEM

VCT
DR
PET
SPECT
IMAGING

14

Anatomical

Physiological

Molecular

Disease Process

Organ System
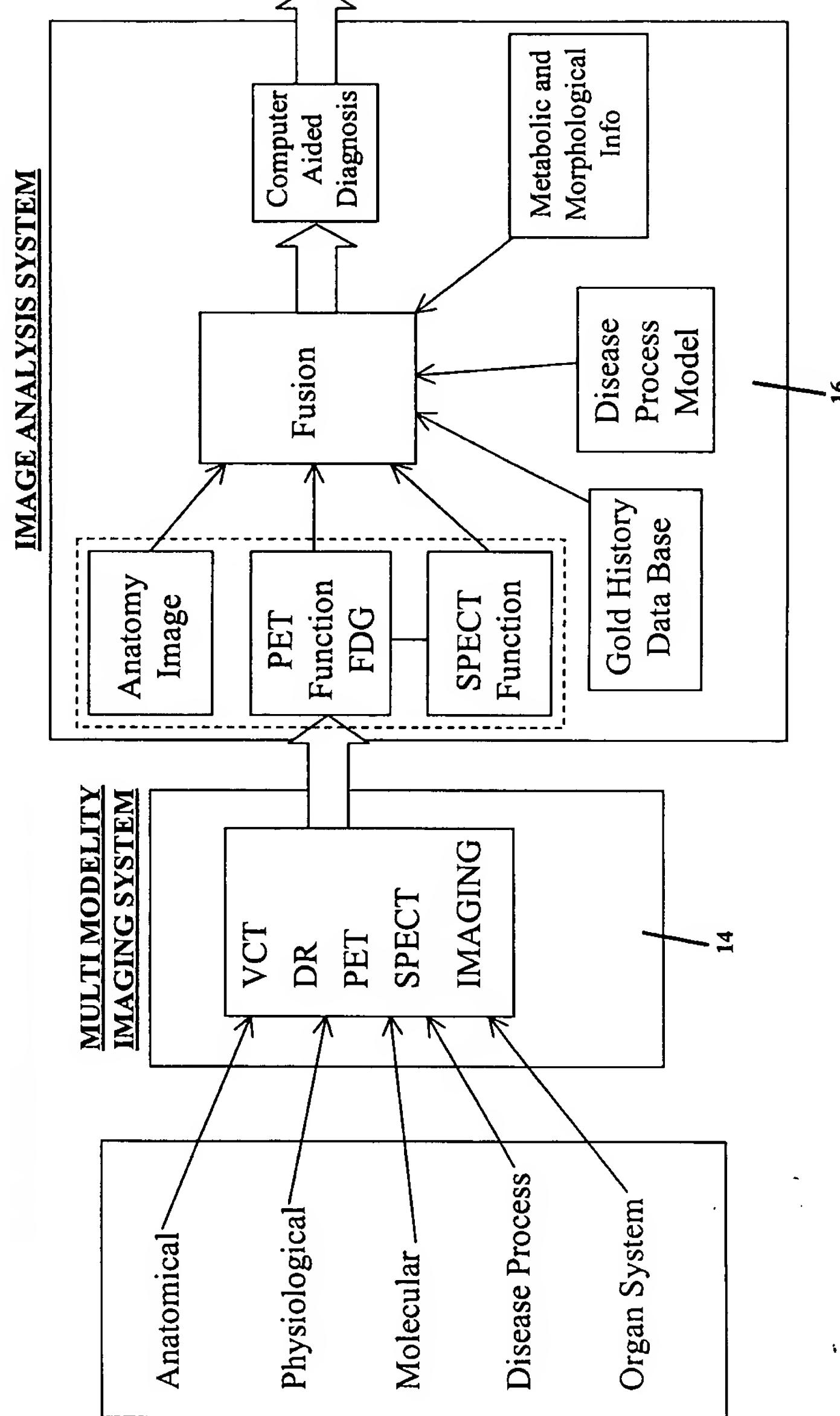
Figure 36

Interventional Image Control System

Multi-Modality Images → Image Analysis & Display System — 64

Interventional Image Control System — 70

Interventional Planning System — 200

Image Comparison and Guidance System — 202

Operator Real Time Image Display & Analysis System — 66

Gating Control System — 48

Interventional Robotic System — 58
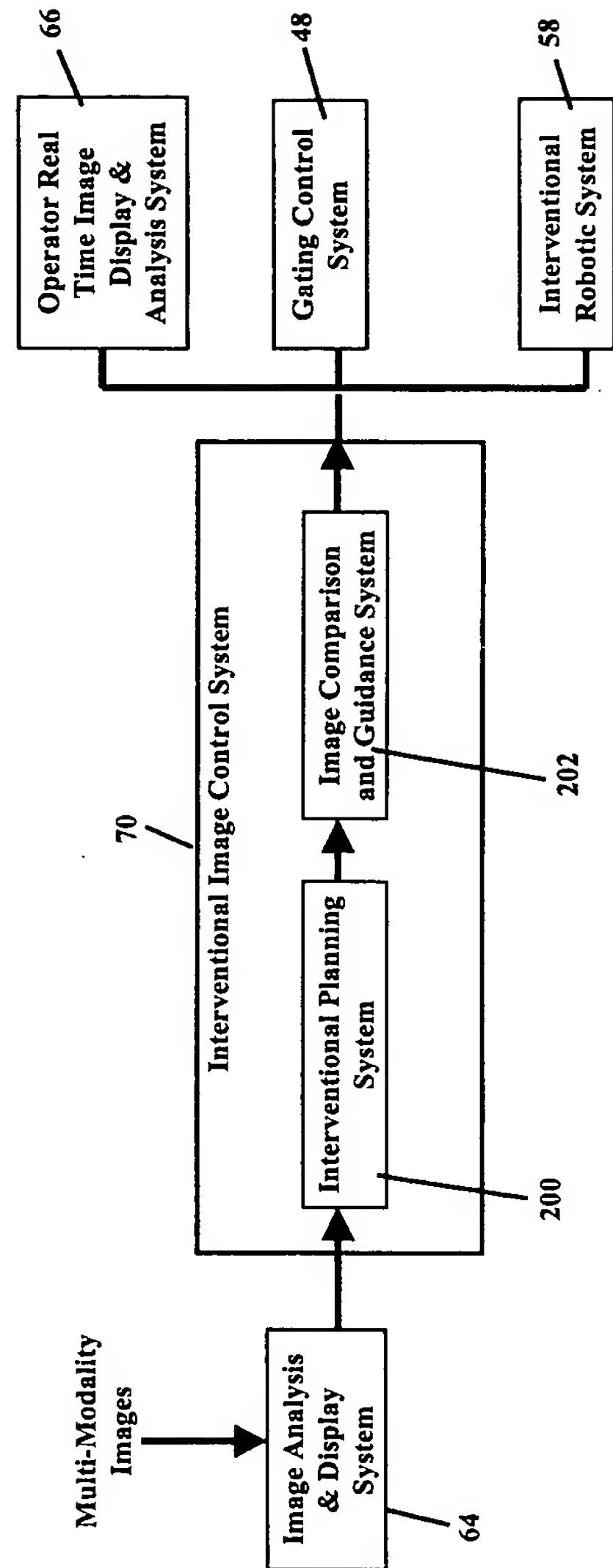
## Figure 37

Multi-Modality Imaging with Independent X-Ray VCT, PET, and NM/SPECT Image Acquisition System
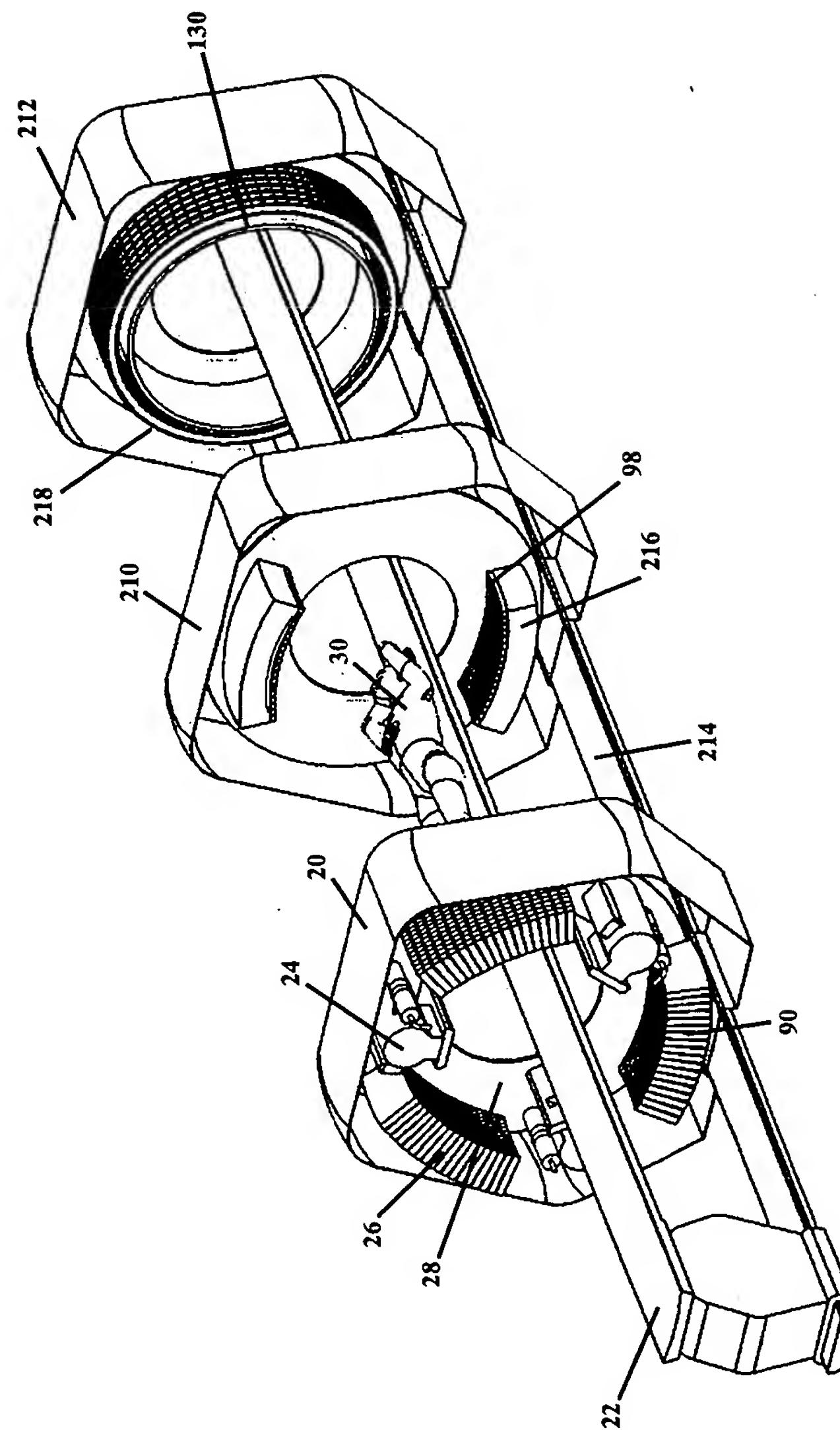
Figure 38

Multi-Modality Imaging with Independent X-Ray Single Head VCT, PET, and NM/SPECT Image Acquisition System

212

130

218

210

98

30

216

20

214

24

90

28

26

22
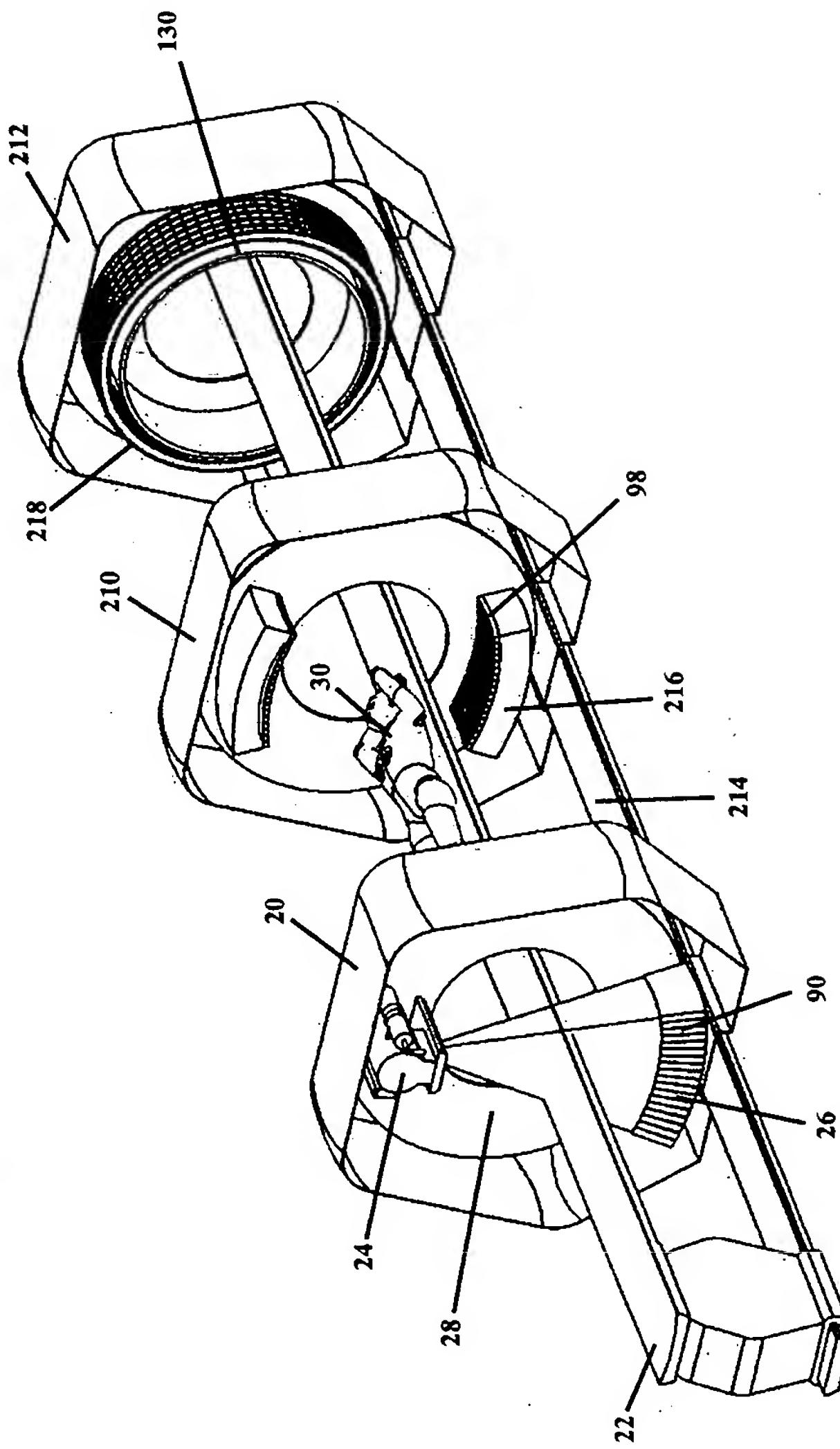
Figure 39

Multi-Modality Imaging with Independent X-Ray 4th Generation VCT, PET, and NM/SPECT Image Acquisition System
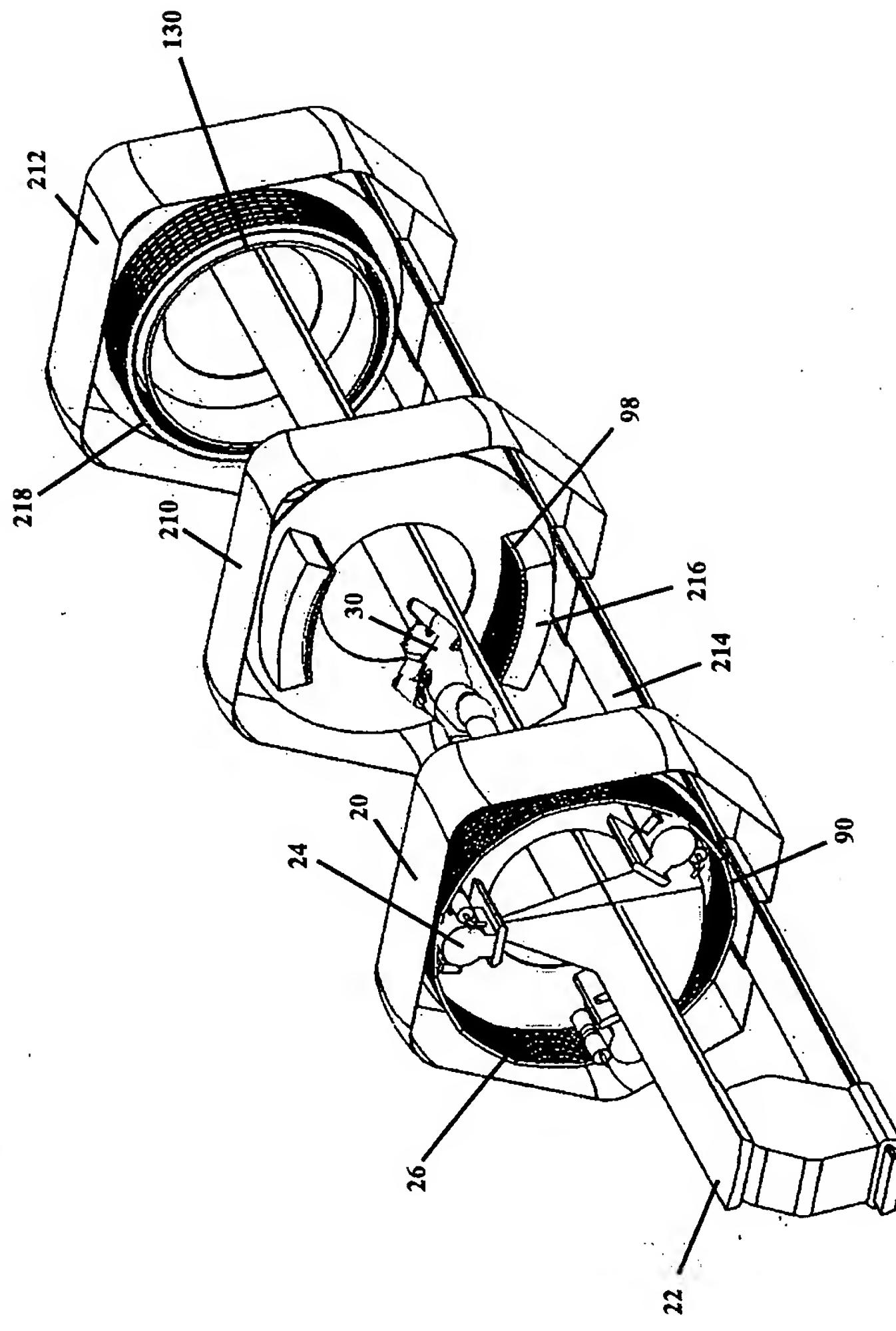
Figure 40

# Multi-Modality Imaging System with Stationary
Focused 2D Curved Detector for VCT, PET and NM/SPECT Imaging
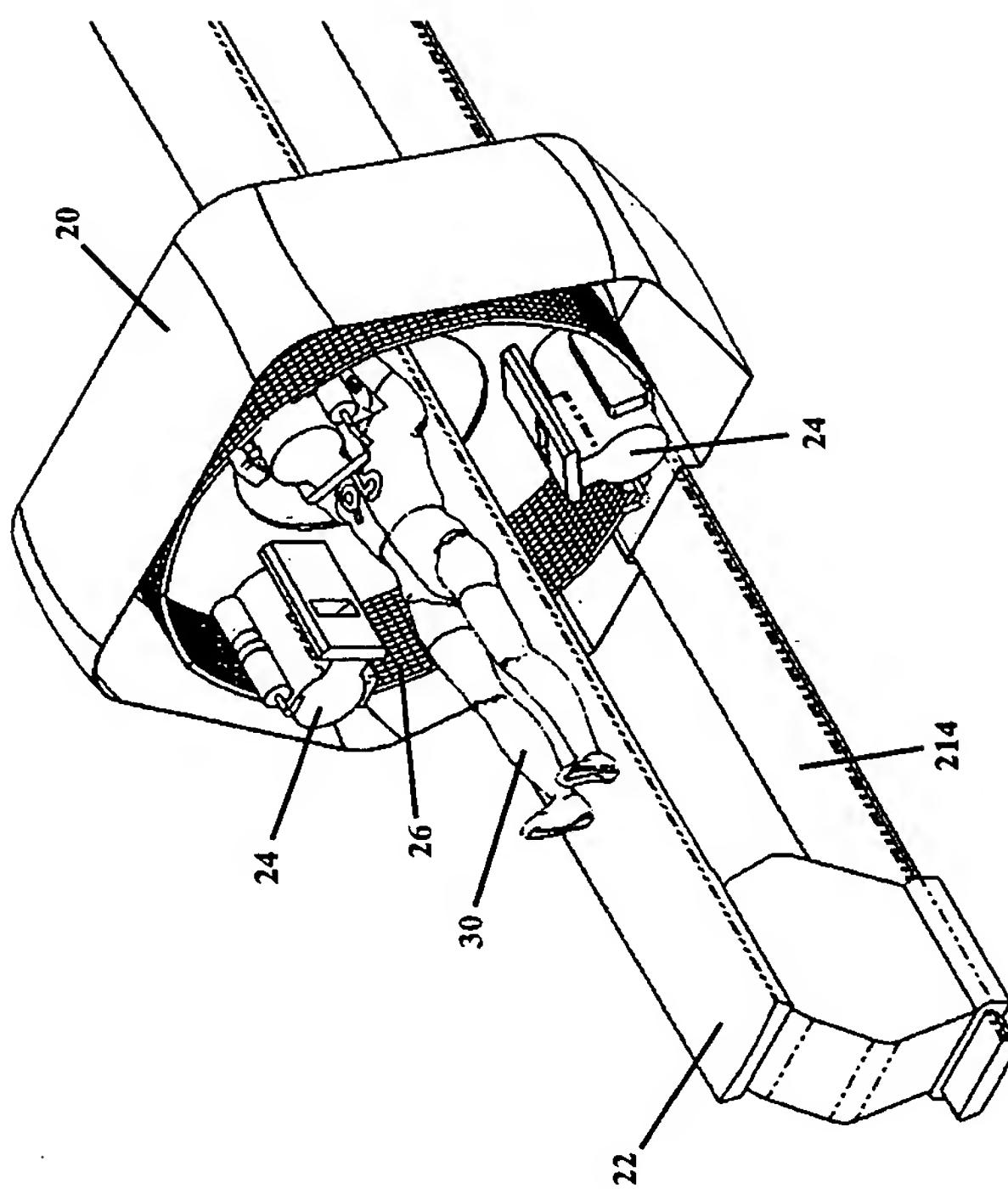
Figure 41

Multi-Modality Imaging with Common Gantry and Independent X-Ray VCT, PET, and NM/SPECT Image Acquisition System
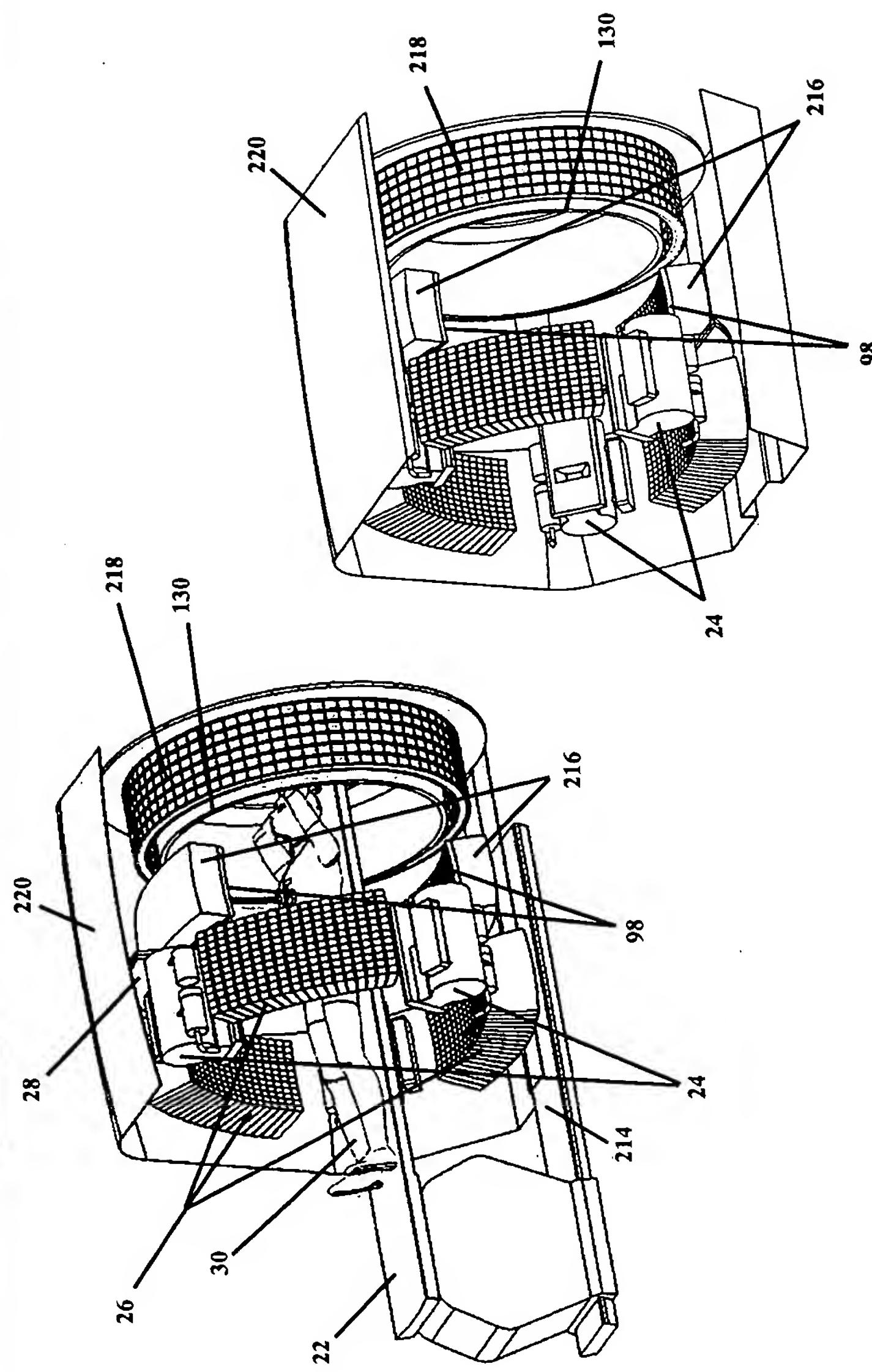
Figure 42

Multi-Modality Imaging with Common Gantry and Independent X-Ray
## Single Head VCT, PET, and NM/SPECT Image Acquisition System
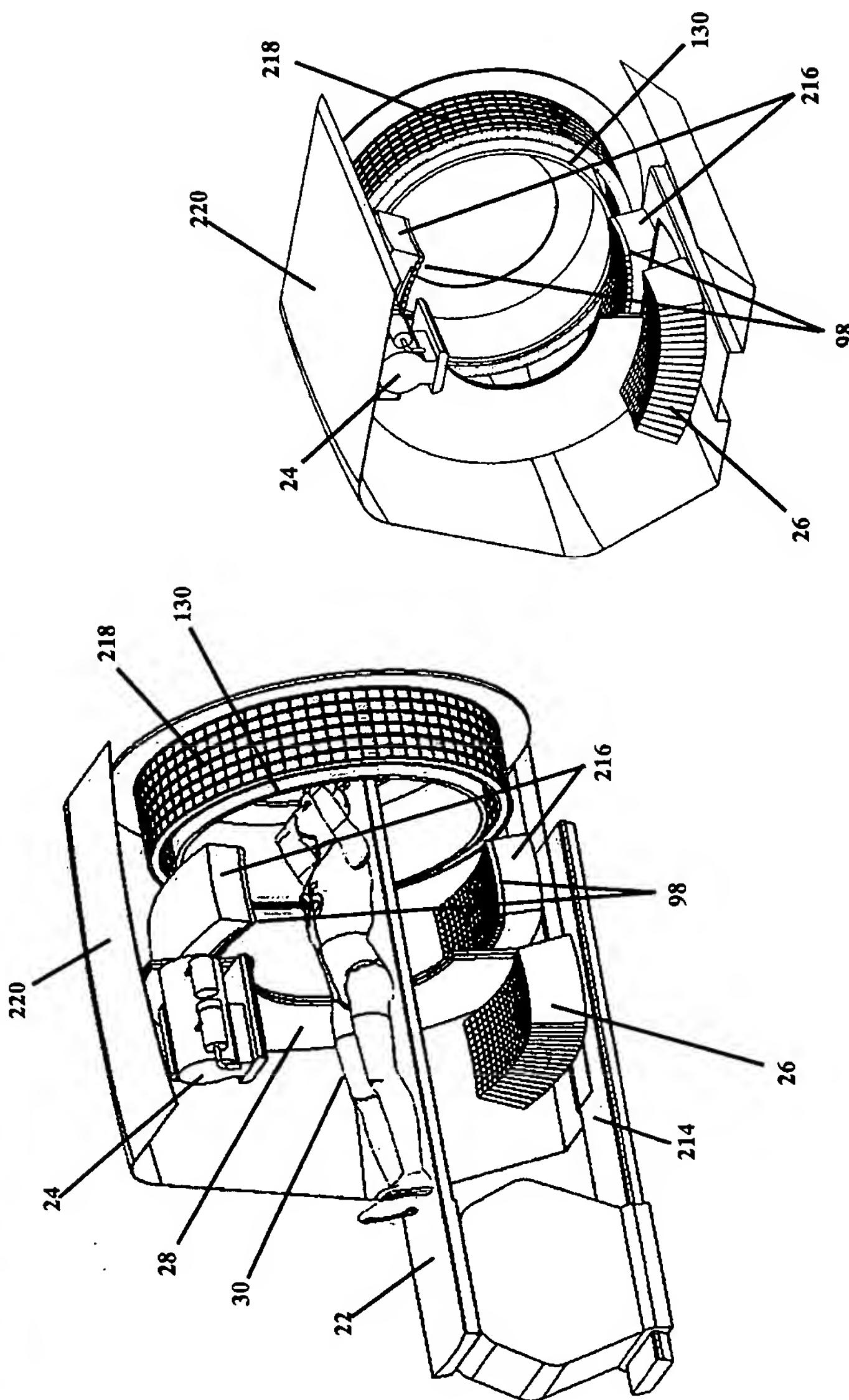
Figure 43

Multi-Modality Imaging with Common Gantry and Independent X-Ray 4th Generation VCT, PET, and NM/SPECT Image Acquisition System
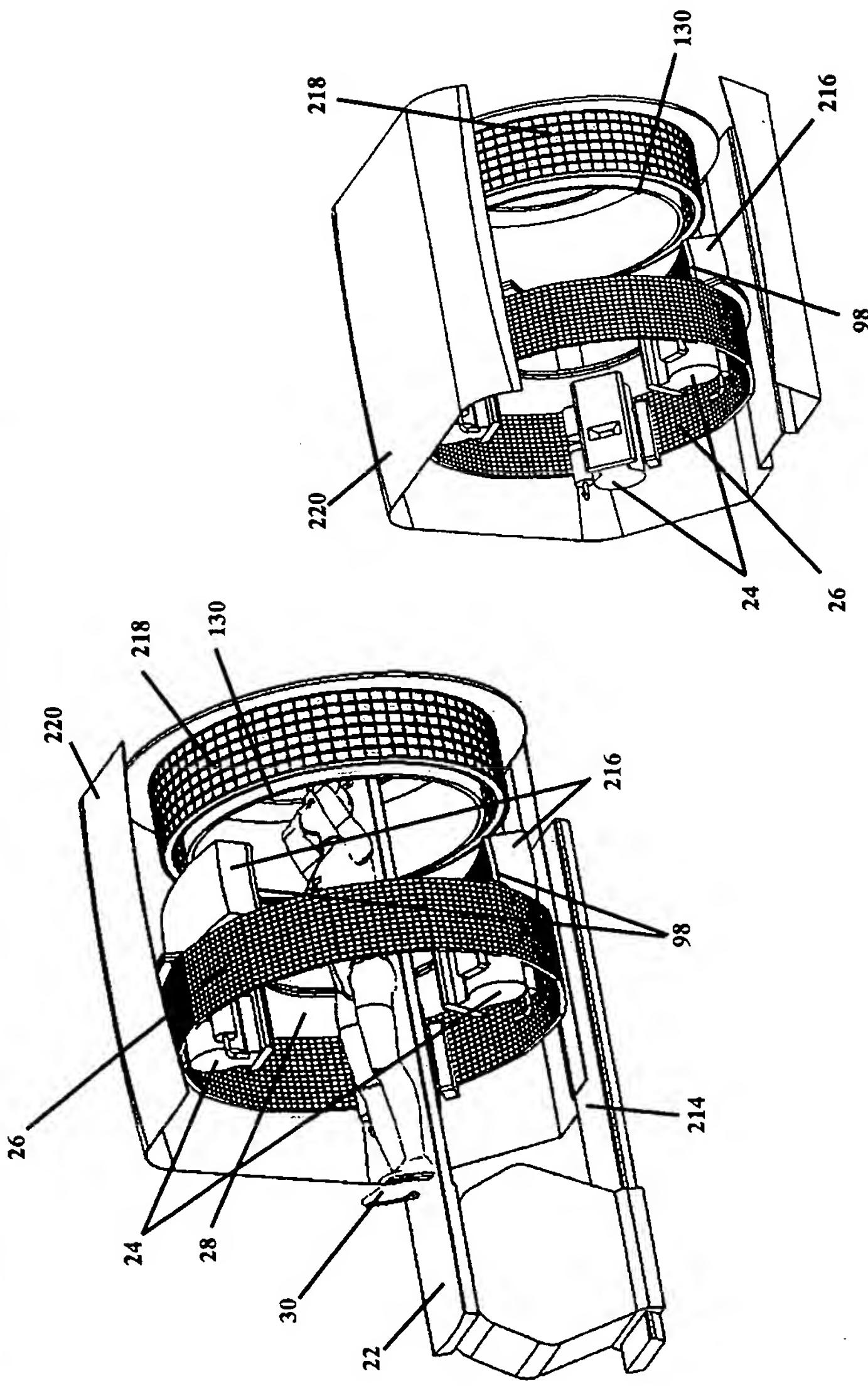
Figure 44

Multi-Modality Imaging with Common Gantry and Independent Single X-Ray 4th Generation VCT, PET, and NM/SPECT Image Acquisition System

Figure 45